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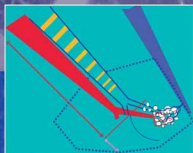
**Diagnostic  
Imaging**

A. L. Baert  
M. Knauth  
K. Sartor

# Computed Tomography of the Lung

**A Pattern Approach**

J. A. Verschakelen  
W. De Wever



Springer

# **MEDICAL RADIOLOGY**

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## **Diagnostic Imaging**

Editors:

A. L. Baert, Leuven

M. Knauth, Göttingen

K. Sartor, Heidelberg

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J. A. Verschakelen · W. De Wever

# Computed Tomography of the Lung

**A Pattern Approach**

Foreword by  
A. L. Baert

With 157 Figures in 356 Separate Illustrations, 43 in Color and 32 Tables

 Springer

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# Foreword

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Most radiologists are involved on a daily basis in the performance and interpretation of CT studies of the lung, one of the most frequent radiological examinations in routine practice.

The currently available state-of-the-art MDCT technology enables us to study and display lung anatomy and gross pathology up to the level of the secondary pulmonary nodule in an exquisite way.

Prof. J.A. Verschakelen and Dr. W. De Wever have taken an original but highly didactic approach to explaining and teaching the CT features of lung diseases and other diseases with a pulmonary component.

The numerous superb colour drawings, together with the well chosen high resolution CT images, enable the reader to better understand the CT changes in patients with pulmonary diseases, to recognise characteristic appearances and distribution patterns of the lung parenchyma, and finally how to use these patterns to make a correct diagnosis or to narrow down the number of differential diagnostic possibilities. The fact that all chapters of this book have been authored by the two editors only ensures that the specific concept and approach of this book is well respected throughout the whole volume.

I congratulate the authors, both internationally well known chest radiologists, for writing this excellent and remarkable work. I can strongly recommend it to all trainees in radiology and pneumology, as it provides a perfect guide through the field of HRCT of the lung, as well as to certified medical specialists who want to update their knowledge in CT of the lung.

I am confident that this volume will meet with the same success among readers as many of the previous volumes published in this series.

Leuven

ALBERT L. BAERT

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# Preface

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Computed tomography is generally considered to be the best imaging modality for the assessment of the lung parenchyma. High resolution computed tomography (HRCT) is able to provide very high morphological detail of the normal and abnormal lung parenchyma and has been widely accepted as the imaging gold standard for the lung parenchyma. Many reports have confirmed the high diagnostic value of this technique, especially in the study of widespread diffuse or generalized lung disease, which is due to the HRCT protocol obtaining images at 10- or 20-mm intervals. Spiral CT, and especially multidetector-row spiral CT, has brought about enormous change in the field of cross-sectional imaging and also has significant potential for the study of the lung parenchyma. This procedure is indeed able to generate volumetric high-resolution CT which provides a contiguous, detailed visualisation of the lung parenchyma. This visualisation is no longer limited to the axial plane since multiplanar reformations and three-dimensional volume reconstructions can easily be performed. In addition, high detail imaging of the lung parenchyma is no longer reserved for the less frequently occurring diffuse and interstitial lung diseases, but has now become available for the study of all lung diseases.

Optimal use and interpretation of CT requires good knowledge and understanding of how the normal lung parenchyma looks on CT, why and how this lung parenchyma may be affected by disease and how these changes are visualised on a CT image. Furthermore, in order to have a fruitful discussion with the clinician taking care of the patient and, when appropriate, with the pathologist, it is important that the radiologist knows and understands why abnormalities appear as they do.

Giving the readers a clear understanding of why abnormalities appear as they do is indeed one of the main goals of this book, since this skill will enable them to choose an appropriate differential diagnosis or even suggest a definitive diagnosis, once the CT findings have been correlated with the clinical situation.

We have opted for a concise and didactic approach by reducing the vast amount of information available on this topic to what we think is basic and essential knowledge that allows to recognise and understand the CT signs of lung diseases and of diseases with pulmonary involvement. We have used the pattern approach because it is well established and it is considered a good method to accomplish the main goal of the book. Our approach also has a practical orientation. For this reason, a large section of the book is dedicated to the description of typical and less typical cases. Analyzing these cases will help the reader to exercise pattern recognition and to understand why the diseases present as they do.

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Furthermore, we have decided to reduce the number of authors to ensure that the specific concept and approach of this book is well respected throughout the whole volume. However, we want to emphasize that this book could certainly not have been written without the many informative discussions we had on this topic with radiologists and pulmonologists, both trainees and certified specialists. We want to express our sincere gratitude to each of them. We would especially like to thank Dr Wim Volders for his valuable suggestions. We also thank Professor Albert L. Baert, who gave us the unique opportunity to write this book and to bring it to a successful conclusion.

We hope the reader will enjoy this work and will find it helpful when exploring the perhaps difficult but very exciting CT features of lung diseases and diseases with a pulmonary component.

Leuven

JOHNY A. VERSCHAKELLEN and WALTER DE WEVER

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# Introduction

JOHNNY A. VERSCHAKELEN

The use of computed tomography in the study of lung diseases is well established. Many reports have indeed emphasised its role not only in the detection and diagnosis but also in the quantification and follow-up of both focal and diffuse lung diseases. Moreover, CT has helped to better understand the clinical and pathological course of some diseases while some CT classifications are used now to categorise disease.

CT interpretation, however, remains difficult. CT findings are often not specific and can change during the course of the disease. In addition, the CT changes often have more than one pathological correlate, abnormalities can occur before clinical symptoms develop and clinical symptoms may be present before CT abnormalities become evident. That is why a final diagnosis, especially in a patient with diffuse interstitial lung disease, is often only possible when clinicians, pathologists and radiologists work closely together. To make such cooperation successful, it is very important that the pathological correlate of the CT changes is very well understood. In fact, when looking at the CT features, at least at a submacroscopic level, one should be able to predict the pathological changes, but also vice versa: when reading the report of the pathologist, one should be able more or less to imagine how the CT scan could look. Today's CT techniques can offer such good image quality that these correlations between CT and pathology become easier. Not only the improved detail of high resolution computed tomography, but also the ability to produce highly detailed reformatted images is responsible for this.

CT is now able to study the lung anatomy and pathology at the level of the secondary pulmonary lobule, which is a unit of lung of about 0.5–3 cm. CT can discover different components of this secondary pulmonary lobule, especially when they are abnormal. This is particularly helpful in the study of the distribution pattern of the disease since the airway, vascular, lymphatic and interstitial pathways of distribution can, because of their specific relation to

the secondary pulmonary lobule, often be identified and differentiated from each other. This explains why the diagnosis of lung disease with CT is to a large extent based on the study of the distribution of the disease.

Another important element to diagnosing lung disease with CT is the study of the disease appearance pattern. Recognition of the appearance pattern often allows developing an appropriate differential diagnosis list including all the major categories of disease that might lead to the identified pattern. Although the recognition of a pattern may be easy and straightforward, some lung changes are difficult to categorise because patterns are very often mixed or change during the course of the disease. Nevertheless, in order to make a diagnosis or an adequate differential diagnosis list, the exercise of trying to categorise the CT changes into one or more specific patterns should always be done. This is certainly true when diffuse lung disease is studied, but is often also very helpful when focal lung disease or diseases involving only a few lung areas are encountered.

The subtitle of this book is “A pattern approach”. Indeed an important objective of this book is to help the reader to identify the disease pattern: i.e. the appearance and distribution pattern of the disease. Tools and illustrations are provided that not only help to recognise these patterns but that also help to understand why disease can present with a particular pattern. The book is organised according to the different appearance patterns that can be encountered on a CT scan of the lungs. After an introductory chapter on how a CT of the lung should be approached, several chapters describe the different patterns in detail: (1) increased lung attenuation, (2) decreased lung attenuation, (3) the nodular pattern and (4) the linear pattern. Once the appearance pattern(s) is/are determined, the distribution pattern should be identified. In each chapter, a great deal of attention is therefore provided on how combining disease pattern and distribution pattern can

lead to a diagnosis or a narrow differential diagnosis list. Diagrams are provided for this purpose. A good understanding of the disease and distribution pattern is only possible when the anatomy of the lung is well known. That is why a chapter on basic anatomical considerations is included and precedes the chapters dealing with the different patterns. Finally, the CT features of the most frequently occurring focal and especially diffuse lung diseases will be shown and their appearance and distribution patterns will be listed.

#### ● Basic objectives of the book

- Learn to detect and understand the CT changes in patients with lung disease
  - Learn to recognise and to determine the different appearance and distribution patterns of lung disease
  - Learn to use these patterns to make a diagnosis or to narrow the differential diagnosis list
-

# Basic Anatomy and CT of the Normal Lung

JOHNY A. VERSCHAKELN and WALTER DE WEVER

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## 2.1

### Introduction

Good knowledge of lung anatomy is mandatory to understand the CT features of lung diseases, not only because it permits a better understanding of the CT features of the disease (appearance pattern), but also because it helps to understand the specific distribution in the lung of the disease (distribution pattern). Comprehensive knowledge of the lobes and segments of the lung has of course always been a

very important part of radiologists' armamentarium, but it was the introduction of CT and especially thin-slice CT that made the significance of the subsegmental lung anatomy apparent. Indeed, the high anatomic detail obtained with thin-slice CT allows the recognition of anatomical structures at a subsegmental level and the identification of lung units as small as the secondary pulmonary lobule. These secondary pulmonary lobules have turned out to be very important in the interpretation of lung changes seen on CT and abnormalities of these units are more or less the building blocks of which the CT patterns are constructed. In addition, good knowledge of the anatomy of the secondary pulmonary lobule is also very useful to determine the distribution pattern of the disease. Differential diagnosis of lung disease can indeed be narrowed when one is able to decide whether the disease very likely is located in or around the airways, the blood vessels, the lymphatics or the lung interstitium.

The first section of this chapter will discuss the basics of lung anatomy. In the second section, a short description will be given on the relationship between lung anatomy and distribution of disease, while a third section discusses the CT features of the normal lung.

## 2.2

### Basic Anatomical Considerations

This section starts with a discussion on those aspects of the anatomical organisation of the bronchial tree, the pulmonary blood vessels and the lymphatics, that are important in using and interpreting CT scans of the lungs. Subsequently, the anatomy of the interstitium will be discussed and finally attention will be given to the subsegmental structures of the lung, particularly the anatomy of the secondary pulmonary lobule.

### 2.2.1 Anatomic Organisation of the Tracheobronchial Tree

Airways divide by dichotomous branching with approximately 23 generations of branches identifiable from the trachea to the alveoli (Fig. 2.1; Table 2.1). This dichotomy is asymmetric, which implies that although division of the bronchus into two branches is usual, variation in both number and size of the branches is common (HORSFIELD and CUMMING 1968). The trachea divides into main bronchi that divide into lobar bronchi. The lobar bronchi divide into segmental bronchi that in turn divide into subsegmental bronchi. These bronchi divide into several generations of smaller bronchi and finally the terminal bronchi are reached. These terminal bronchi divide into bronchioles.

Bronchioles differ from the bronchi in that the bronchi contain cartilage and glands in their walls; whereas the bronchioles do not. The bronchioles include two categories: the membranous bronchioles (lobular and terminal) and the respiratory bronchioles. The term “small airways” is often also used to describe these bronchioles and small airway disease is then defined as the pathological condition in which these bronchioles are affected.

At this point, it should be emphasised, however, that an internal diameter of 2 mm is another often used division between small and large airways. Although both definitions do not correspond because cartilage may be found in some peripheral airways less than 1 mm in diameter, the latter definition is more practical and more frequently used in radiological literature. The lobular bronchioles enter the core of the secondary pulmonary lobule and divide into a number of terminal bronchioles according to the size of the lobule. These terminal bronchioles represent the most distal purely conducting portion of the tracheobronchial tree; that is they conduct air without being involved in gas exchange. The terminal bronchioles give rise to the respiratory bronchioles, which are so designated because alveoli bud directly from their walls. Hence, respiratory bronchioles not only are conducting but are also involved in gas exchange. The respiratory bronchioles give rise to alveolar ducts. In contrast to the respiratory bronchioles where alveoli only rise occasionally from the wall, these alveolar ducts have so many alveoli originating from their wall that there is virtually no wall structure between the alveolar orifices. The alveolar ducts finally lead into the alveolar sacs containing several alveoli (BOYDEN 1971).

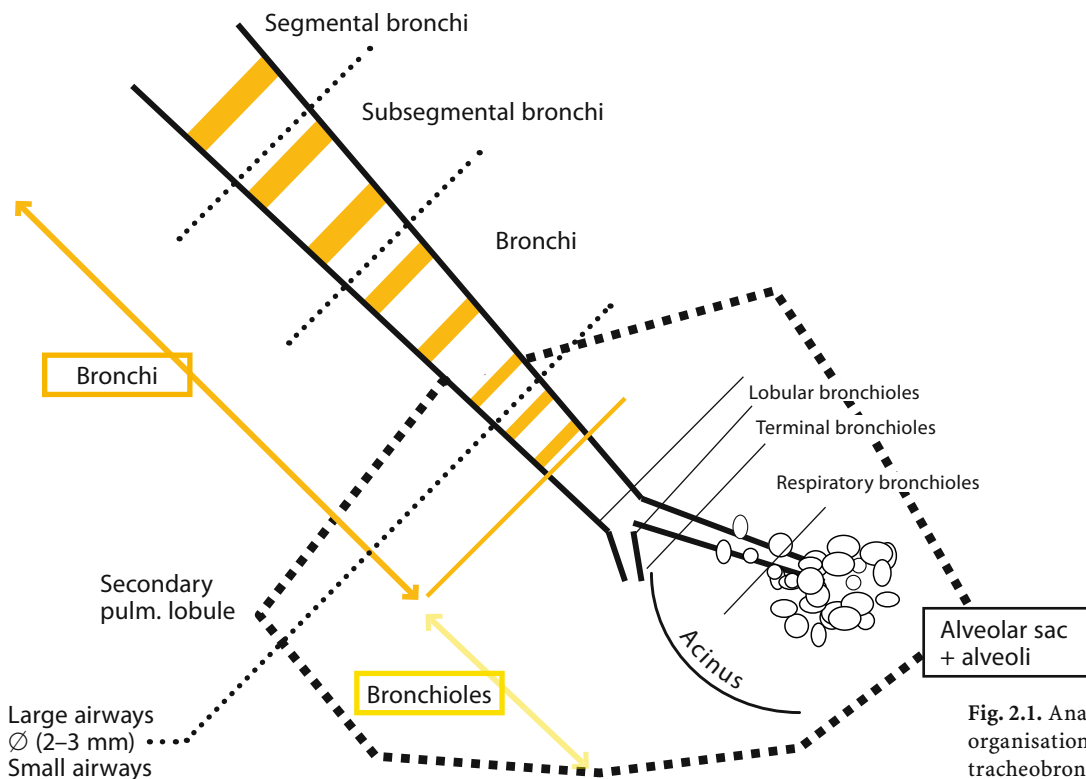


Fig. 2.1. Anatomic organisation of the tracheobronchial tree



**Table 2.1.** In this table the different generations of airways with their approximate diameter are listed

Structure	Generation	Diameter (mm)
Trachea	0	25
Main bronchi	1	11–19
Lobar bronchi	2–3	4–13
Segmental bronchi	3–6	4–7
Subsegmental bronchi	4–7	3–6
Bronchi	6–8	1.5–3
Terminal bronchi		1
Bronchioles	9–15	0.8–1
Lobular bronchioles		0.8
Terminal bronchioles	15–16	0.6–0.7
Respiratory bronchioles	17–19	0.4–0.5
Alveolar ducts and sacs	20–23	0.4
Alveoli		0.2–0.3

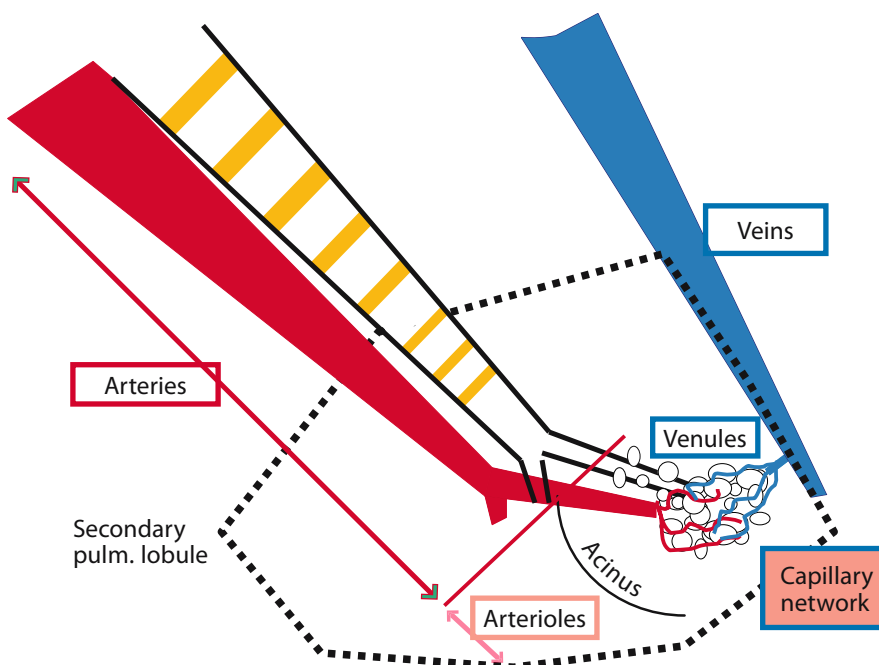
The lobular bronchioles enter the core of the secondary pulmonary lobule and divide into a number of terminal bronchioles according to the size of the lobule.

Adjacent alveoli originating from different air sacs are known to communicate directly with one another through the pores of Kohn. Familiarity with these tiny communications is necessary to understand the pathology of diseases involving the alveoli (CULINER and REICH 1961; HOGG et al. 1969; LIEBOW et al. 1950; VAN ALLEN and LINDSKOG 1931). The canals of Lambert communicate distal bronchioles, particularly preterminal bronchioles with alveoli (LAMBERT 1955).

### 2.2.2

#### Anatomic Organisation of the Blood Vessels

The arteries of the human lung accompany the airways and their pattern of division is similar to the branching of the airways; hence for each airway branch there is a corresponding artery (ELLIOTT and REID 1965) (Fig. 2.2). However, there are many artery branches that do not accompany any portion of the airway and that are sometimes called supernumerary arteries. In fact, the ratio of the parent airway to its branches is between two and three while for the pulmonary artery system the ratio is between three and four (FRASER and PARE 1977). The vessels accompanying the bronchi are considered to be elastic arteries because they have well-developed elastic laminae. The vessels accompanying the bronchioles down to the level of the terminal bronchioles are generally considered to be muscular



**Fig. 2.2.** Anatomic organisation of the blood vessels

arteries because they contain fewer elastic laminae. The vessels distal to the terminal bronchioles lose their continuous muscular coat and have a single elastic lamina; they are called pulmonary arterioles. The capillary network originates from the arterioles and surrounds the alveoli. The high number of individual very small vessels make this capillary network look like a thin, continuous layer of blood covering alveoli interrupted by columns of connective tissue that act as supports (WEIBEL 1979).



The arteries of the human lung accompany the airways and their pattern of division is similar to the branching of the airways.

Distal to the capillary network, the pulmonary venules are formed, which merge into pulmonary veins at the periphery of the secondary pulmonary lobule. These pulmonary veins run through the interlobular septa and then through more central connective tissue sheaths to the left atrium.



The pulmonary veins are formed by confluence of pulmonary venules at the periphery of the secondary pulmonary lobule and run through the interlobular septa and through more central connective tissue sheets.

The bronchial arteries belong to a different arterial system that originates from the systemic circulation. Except for those distributed to the pleura, these bronchial arteries accompany the bronchi to the level of the terminal bronchiole. At this point they ramify into a capillary plexus, which is intimately integrated into the bronchial wall. In the lung periphery, the bronchial arteries also anastomose and are drained by the pulmonary venous system (LAUWERYS 1971; MILLER 1947). The bronchial veins exist as a distinct set of vessels only in the hilar region, where they drain blood from the hilar structures and walls of the major bronchi into the azygos and hemiazygos system. It is not clear whether there are also bronchial veins at the periphery of the lung that drain blood from the bronchial capillary bed into pulmonary veins. However, it is generally accepted that the final drainage of the bronchial arterial flow is by way of the pulmonary veins.

### 2.2.3

#### Anatomic Organisation of the Lymphatics

The pulmonary lymphatics absorb the normal transudate from the capillary bed and carry it from the interstitial space to the central circulation (Fig. 2.3). There are two intercommunicating networks of lymph flow. First there is the rich subpleural plexus, which is connected to and drained by the septal lymphatic channels. These channels follow interlobular septa

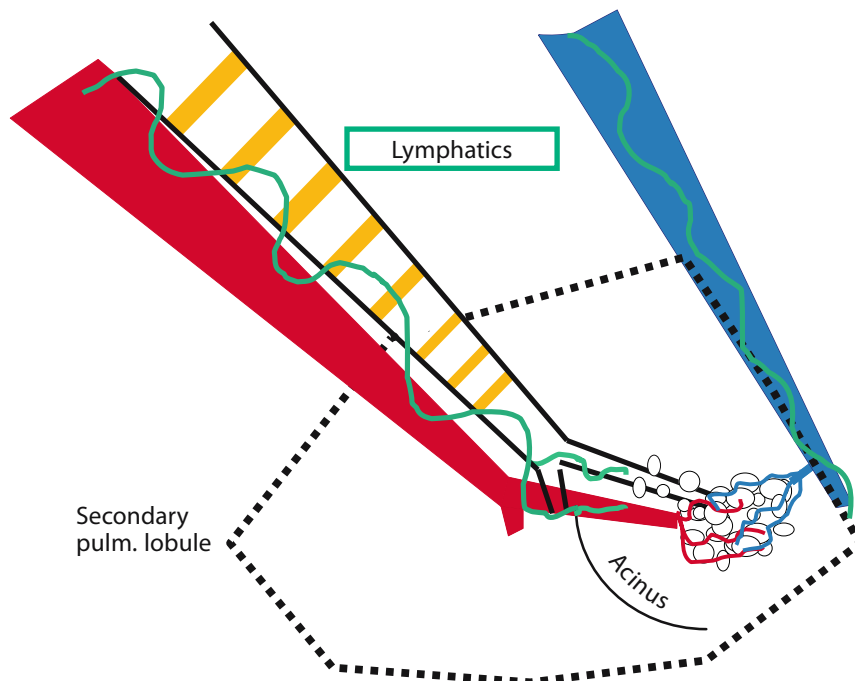


Fig. 2.3. Anatomic organisation of the lymphatics

and progress into axial connective tissue sheaths around veins as they progress centrally. Another system of lymphatic channels is found in the axial connective tissue around arteries, bronchi and bronchioles. A curious fact is that no lymphatics are found in alveolar walls. This is indeed curious considering that their job is to mobilise fluid that is escaping from the capillaries. So this fluid has to migrate towards the pulmonary lymphatics, which are located in the peribronchiolar and the perivascular spaces, the interlobular septa and the pleural network (WEIBEL and BACHOFEN 1979). Consequently, one part of the lymph fluid is removed first centrifugally and then centripetally while another part is removed directly towards the hilum. It is not clear whether the capillary pressure forces this fluid through the alveolar walls to the lymphatics that act as efficient sumps or whether the fluid is sucked into the lymphatics by more negative interstitial pressure (WEIBEL and BACHOFEN 1979). Perhaps both mechanisms are operational.

There are two intercommunicating networks of lymph flow

- The subpleural plexus connected to septal lymphatic channels
- The axial plexus around arteries, bronchi and bronchioles

## 2.2.4

### The Pulmonary Interstitium

The pulmonary interstitium is the supporting tissue of the lung and can be divided into three component parts that communicate freely: (1) the peripheral connective tissue; (2) the axial connective tissue, and (3) the parenchymatous connective tissue (WEIBEL and GIL 1977) (Figs. 2.4, 2.5).

#### 2.2.4.1

##### Peripheral Connective Tissue

The peripheral connective tissue includes the subpleural space and the lung septa. The septa are fibrous strands that penetrate deeply as incomplete partitions from the subpleural space into the lung not only between lung segments and subsegments but also between secondary pulmonary lobules and acini (WEIBEL 1979). So the pleura is in anatomic continuity with the different lung septa including the interlobular septa and the septa between the acini. A more detailed description of the secondary pulmonary lobule, the acinus and the interlobular septa, as well as the septa between acini will be given in Sect. 2.2.5.

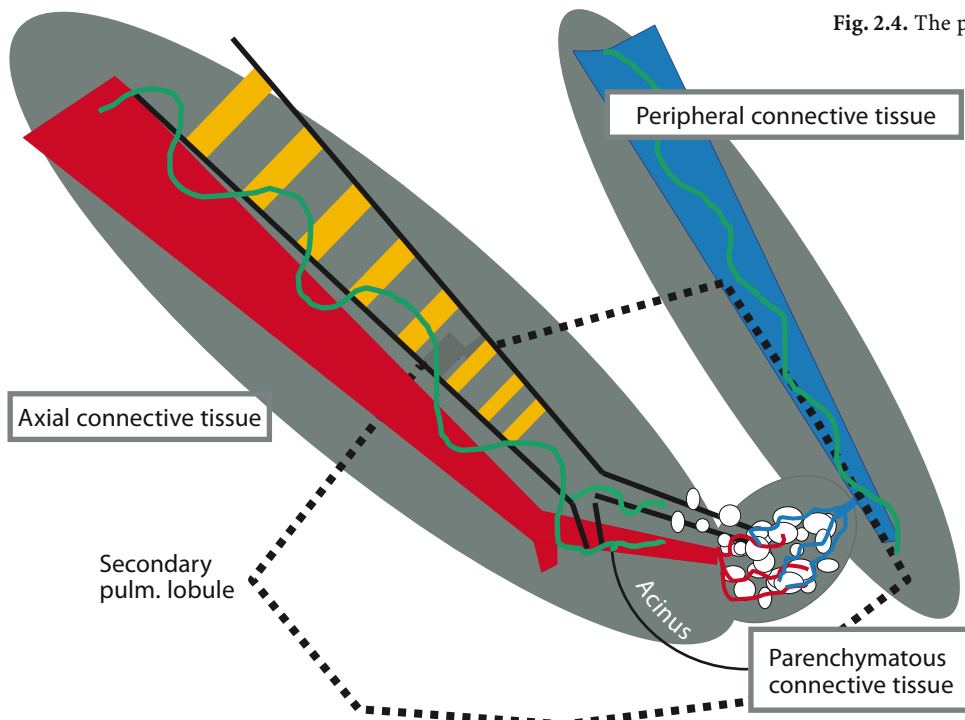


Fig. 2.4. The pulmonary interstitium

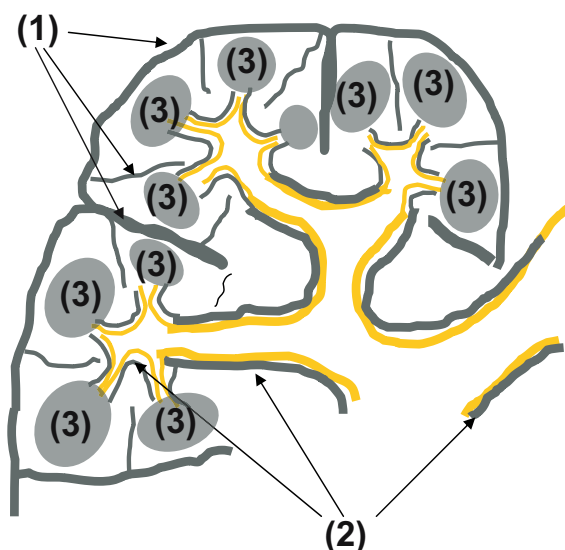


Fig. 2.5. The pulmonary interstitium can be divided into three component parts that communicate freely: (1) the peripheral connective tissue; (2) the axial connective tissue; (3) the parenchymatous connective tissue

#### 2.2.4.2

##### Axial Connective Tissue

The axial connective tissue is a system of fibres that originates at the hilum, surrounds the bronchovascular structures and extends peripherally. It terminates at the centre of the acini in the form of a fibrous network that follows the wall of the alveolar ducts and sacs (WEIBEL 1979). The alveoli are formed in the meshes of this fibrous network.

#### 2.2.4.3

##### Parenchymal Connective Tissue

At their peripheral limits, the alveoli and the capillaries are in close contact in order to allow gas diffusion. Nevertheless, elastic and collagen fibres are present also and are part of the parenchymatous connective tissue. These fibres appear at the side of the capillaries; in fact the capillary is wound around these fibres like a snake around a pole. In this way, on one side of the capillary the basement membrane of this capillary is fused to the alveolar basement membrane to form a thin sheet across which diffusion takes place, while on the other side a septal fibre separates both structures. These fibres extend from the axial to the peripheral connective tissue and are short and thin (WEIBEL 1979).

The pulmonary interstitium is the supporting tissue of the lung and can be divided into three component parts that communicate freely:

- The peripheral connective tissue;
- The axial connective tissue
- The parenchymal connective tissue

#### 2.2.5

##### The Subsegmental Structures of the Lung and the Secondary Pulmonary Lobule

Three units of lung structure have been described at the subsegmental level of the lung: the primary pulmonary lobule, the acinus and the secondary pulmonary lobule (GAMSU et al. 1971; LUI et al. 1973; MILLER 1947; PUMP 1964, 1969; RECAVARREN 1967; SARGENT and SHERWIN 1971; WEIBEL and TAYLOR 1988; ZISKIND et al. 1963). Since the primary pulmonary lobule cannot be demonstrated by CT in either normal or abnormal states, this unit is of no practical radiological significance and will be discussed only briefly. More attention will be given to the two other structures. Indeed, while in diseased lung the acinus sometimes can be identified with CT, the secondary pulmonary lobule or parts of it can be seen very often with this technique, even when the lung is only mildly diseased or normal. That is why the secondary pulmonary lobule is the ideal unit of subsegmental lung organisation with which the CT and pathologic abnormality can be correlated and why a basic understanding of its anatomy is mandatory to understand the CT patterns seen in various disease states.



The secondary pulmonary lobule is the ideal unit of subsegmental lung organisation with which the CT and pathologic abnormality can be correlated.

#### 2.2.5.1

##### Primary Pulmonary Lobule

Miller originally described the primary pulmonary lobule and defined it as the lung unit distal to the

respiratory bronchioles (MILLER 1947). The primary pulmonary lobule consists of alveolar ducts, alveolar sacs and alveoli. According to Wyatt et al., approximately 30–50 primary pulmonary lobules can be found in one secondary pulmonary lobule (WYATT et al. 1964).

### 2.2.5.2

#### Acinus

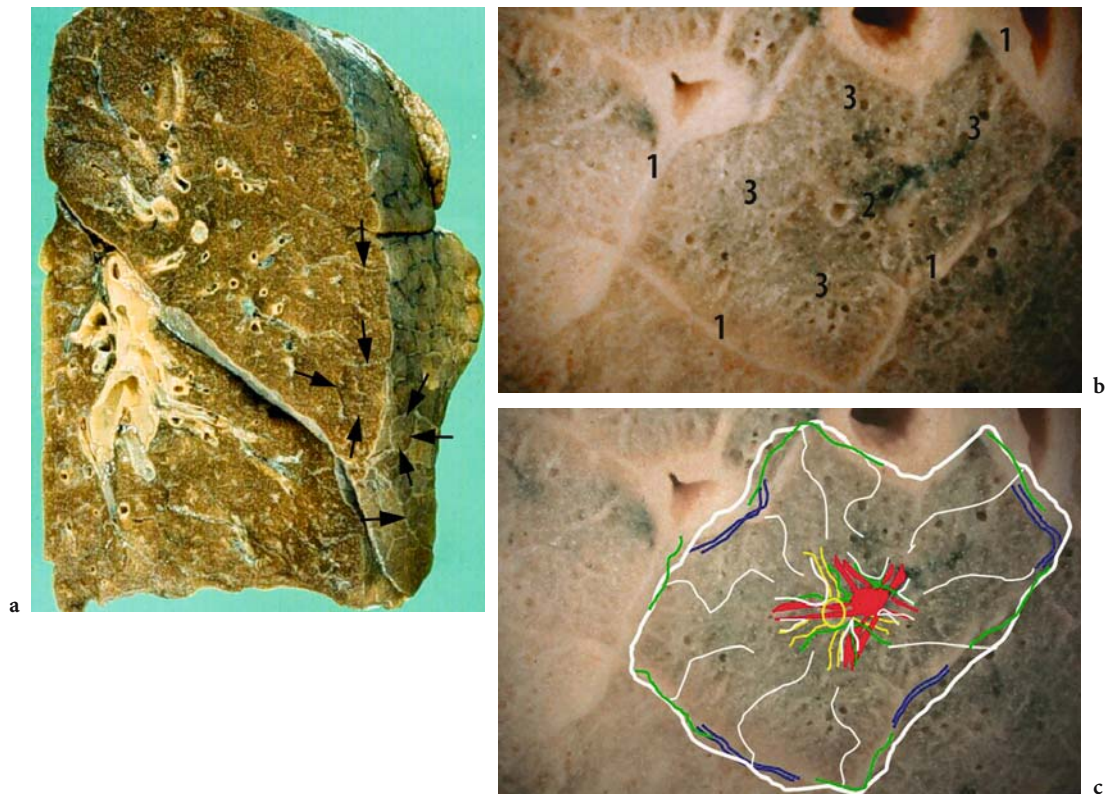
Although several different definitions of the acinus can be found, a commonly accepted, and also for CT interpretation conceptually appropriate, definition describes the acinus as the portion of lung distal to a terminal bronchiole and supplied by a first-order respiratory bronchiole or bronchioles (GAMSU et al. 1971; RECAVARREN et al. 1967; REID and SIMON

1958). Because respiratory bronchioli contain alveoli in their wall, the acinus is the largest unit in which all airways participate in gas exchange. The reported number of acini in one secondary pulmonary lobule varies considerably in different studies and numbers are found between 3 and 12. The diameter of an acinus has been reported to be between 5 and 10 mm (PUMP 1969; SARGENT and SHERWIN 1971).

### 2.2.5.3

#### Secondary Pulmonary Lobule

The secondary pulmonary lobule is defined as the smallest unit of lung structure margined by connective tissue septa (HEITZMAN 1984) (Fig. 2.6). It is supplied by a group of terminal bronchioles, is irregularly polyhedral in shape and is approximately



**Fig. 2.6a–c.** **a** Sagittal section through the lung. Several interlobular septa can be recognised both in the lung parenchyma and at the lung surface (arrows) demarcating secondary pulmonary lobules. **b** The secondary pulmonary lobule has three principal components: (1) the interlobular septa, (2) the centrilobular region and (3) the lobular lung parenchyma. **c** The interlobular septa contain pulmonary veins (blue) and lymphatics (green) surrounded by connective tissue (white). The centrilobular region contains bronchiolar branches (yellow) with their accompanying arteries (red) with adjacent to them some supporting connective tissue (white) and some lymph vessels (green). The lobular parenchyma consists of functioning lung supported by connective tissue septa (white) and stroma. Figure 2.6a appears courtesy of B. Vrugt (Dept. of Pathology, Martini Hospital Groningen, The Netherlands). Part of Figures 2.6b and c appear courtesy of E. Verbeken (Dept. of Pathology, University Hospitals Leuven, Belgium)



1–2.5 cm on each side (REID and SIMON 1958). Although the overall configuration of the secondary pulmonary lobule and its relationship to other lobules appears to be almost entirely random, the organisation of the individual anatomic components of the lobule is quite precise and is similar from lobule to lobule.

The secondary pulmonary lobules are demarcated from each other by interlobular connective tissue septa. From these interlobular septa, fibrous strands penetrate into the lobule between the acini (WEIBEL 1979). The interlobular septa are also continuous peripherally with the pleura (Fig. 2.6a). These interlobular septa are, however, not homogeneously developed in the lung. The septa in the upper lobes tend to be longer and more randomly arranged, whereas in the lower lung fields they appear to be shorter and more horizontally oriented perpendicular to the pleural surfaces.

These connective tissue septa are also better developed at the lung periphery than in the central portions of the lung. But even at the lung periphery, the interlobular septa do not always constitute a totally intact connective tissue envelope surrounding the secondary pulmonary lobule. There are indeed occasional defects in the septa allowing communication between lobules (HEITZMAN 1984). These defects have radiological significance for the concept of collateral airflow on a segmental level. Indeed collateral airflow can maintain lung segments in an inflated state despite obstruction of their bronchi. It is believed that the pores of Kohn and the canals of Lambert are responsible for this phenomenon. If there were no defect in the interlobular septa collateral airflow would only be possible within the secondary pulmonary lobule.

As mentioned earlier, the airway component of the lobule is supplied by a group of terminal bronchioles. However, it is difficult to define which bronchial structures precisely supply the lobules (IRON et al. 1993). Branching of the lobular bronchiole is irregular dichotomous, which means that when it divides, it most often divides into two branches of different sizes, with one branch nearly the same as the one it arose from and the other smaller (IRON et al. 1993). This lobular bronchiole is distributed with the accompanying artery, which has the same irregular dichotomous branching into the central portion of the lobule. Thus on CT, there often appears to be a single dominant bronchiole and artery in the centre of the lobule, which gives off smaller branches at intervals along its length. These bronchioles progress through the lobule, dividing pro-

gressively from terminal to respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli. The arteries show the same branching pattern and these vessels terminate in the capillary bed, which is distributed throughout the alveolar wall. Blood then flows from the capillary bed into venules, which drain to the periphery of the lobule where they join to form the pulmonary vein. These pulmonary veins course centrally through the interlobular septa.

So branching continues until ultimately the entire lobulus is supplied. Most of the lobular volume is thus airway and airspace. When a secondary pulmonary lobule is cut across, macroscopically numerous small holes are seen at the cut surface (Fig. 2.6). These holes represent respiratory bronchioles as well as some portions of the airway distal to this respiratory bronchiole. Alveolar ducts, alveolar sacs and alveoli are too small to be identified macroscopically but fill up the areas between the holes and are together with the small holes responsible for the porous sponge-like character of the cut surface. At the core of the lobule, a larger airway can be seen corresponding with a terminal bronchiole, either presenting as a larger hole or as a branching tubular structure.

The lymphatics are on one hand found adjacent to the pulmonary artery and airway branches and stop more or less at the level of the respiratory bronchioles and on the other hand in the interlobular septa. No pulmonary lymphatics are found in the alveolar walls.

#### The secondary pulmonary lobule has three principal components (Figs 2.6b,c):

- The interlobular septa that marginate the lobule and that contain the pulmonary veins and lymphatics surrounded by connective tissue.
- The centrilobular region containing the bronchiolar branches that supply the lobule, their accompanying pulmonary arteries and adjacent to them supporting connective tissue and lymph vessels.
- The lobular lung parenchyma is the part of the secondary lobule surrounding the lobular core and contained within the interlobular septa. It consists of functioning lung grouped in 3–12 acini that contain alveoli (organised in alveolar ducts and sacs) and their associated pulmonary capillary bed together with their supplying small respiratory airways and arterioles and with draining veins. This parenchyma is supported by connective tissue stroma.

## 2.3

### Relationship Between Anatomy and Distribution of Disease

A good understanding of the lung anatomy in general and of the anatomy of the secondary pulmonary lobule in particular is extremely useful in understanding the pathology and pathogenesis of most pulmonary disease states.

Inhaled disease particles can theoretically deposit everywhere in the tracheobronchial tree. However, often there is a preferential deposition along the respiratory bronchioles. This is explained by the fact that the cross-sectional area of the total of the airways of the lung increases sharply at the level of the respiratory bronchiole. This large number of branches causes laminar air-flow to slow down markedly. The respiratory bronchioles are branches from the terminal bronchioles. Recognition that these terminal bronchioles are distributed to the central core portion of the secondary pulmonary lobule helps to understand why processes that involve the terminal airways, such as pneumonias, rapidly spread out from the centre to the periphery of the lobule when they involve the more distal airspaces leaving, certainly in a first stage, the septal structures unaffected. Intra-alveolar processes can spread not only through the more proximal airway, but also from alveolus to alveolus through the pores of Kohn. These structures are also believed to be responsible for the collateral air drift. This collateral air drift is thought to prevent or to minimise atelectasis secondary to obstruction of terminal portions of the airway by providing an alternate route for air to reach the lung distal to the obstruction. The air that reaches the alveoli by collateral air drift, however, shows relatively little movement during respiration and the oxygen in this stagnant air becomes absorbed, leading to low oxygen concentrations in alveoli and secondary to hypoxic vasoconstriction. It should be emphasised that collateral air drift not only occurs between adjacent alveoli within one secondary pulmonary lobule but occurs also between lobules, segments and even lobes. This can be explained by the well-known incompleteness of fissures and by the presence of defects in the interlobular septa. The canals of Lambert offer another pathway by which diseases can be distributed and by which collateral airflow can occur.

Also the arterial supply is distributed to the central core portion of the secondary pulmonary lob-

ule, which explains why some pathologic processes involving the pulmonary arterial and capillary bed such as pulmonary infarction and pulmonary haemorrhage initially can present findings of alveolar disease that again involve the secondary pulmonary lobule from its core to its peripheral parts leaving the septal structures unaffected.

On the other hand, diseases that cause interstitial abnormalities and fibrosis will produce thickening of the septa, the alveolar wall and the perivascular and peribronchial connective tissues. Similarly, diseases of the pulmonary lymphatics that run in the interlobular septa and along the vessels and airways will cause thickening of these structures. Since pulmonary veins run in the interlobular septa, it is to be anticipated that disease processes involving the pulmonary veins also initially will appear as interstitial abnormalities.

As we will see further on in this book, the CT interpretation of lung disease is in part based on the recognition of the location of the diseases in relation to these different components of the secondary pulmonary lobule structures.

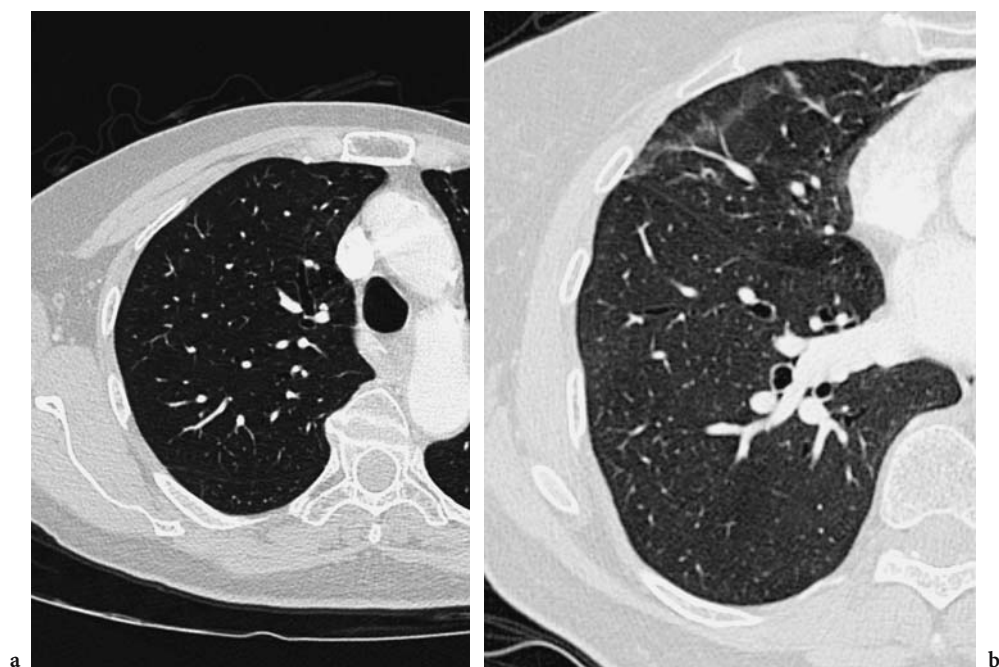
## 2.4

### CT Features of the Normal Lung

#### 2.4.1

#### Large Arteries and Bronchi

The large pulmonary arteries normally appear as rounded or elliptic opacities on CT when imaged at an angle to their longitudinal axis and roughly cylindrical when imaged along their axis (Fig. 2.7). These arteries are accompanied by thin-walled bronchi of which the appearance is also defined by the angle between the scan plane and the axis of the bronchi. When imaged along their axis, bronchi and vessels can show a slight tapering as they branch. The diameter of the artery and its neighbouring bronchus should be approximately equal. However, in the dependent areas vessels are usually slightly larger (Fig. 2.7a). It should be emphasised that in normal subjects, bronchi may appear larger than their adjacent arteries (LYNCH et al. 1993). This is certainly true when the scan traverses the bronchus just before it branches (Fig. 2.7b). The outer walls of both the vessels and the bronchi should be smooth and sharply defined. Also the inner wall of the bron-



**Fig. 2.7a,b.** HRCT of the normal lung at suspended deep inspiration. Note that the vessels are slightly larger in the dependent areas than in the nondependent areas (a). Some bronchi appear larger than their adjacent arteries because the scan traverses the bronchus just before it branches (b)

chi should appear smooth and of uniform thickness. Whether a normal airway is visible or not on a CT scan depends on its size and on the CT technique that is used. As a general rule, airways less than 2 mm in diameter or closer than 1–2 cm to the pleural surface are below the resolution of even HRCT images (KIM et al. 1997; MURATA et al. 1986, 1988; WEBB et al. 1988) (Table 2.1). The presence of visible bronchial structures in the lung periphery (within 2–3 cm of the chest wall) signifies pathologic bronchial wall thickening or ectasia of the small airways.

Assessment of the bronchial wall thickness is often considered a difficult task because it is subjective and depends on the window settings. In addition, what is seen as bronchial wall also includes the peribronchovascular interstitium; consequently, thickness is always a little overestimated. In general and for bronchi distal to the segmental level, the wall thickness of the airways is approximately proportional to their diameter measuring from one-sixth to one-tenth of their diameter (MATSUOKA et al. 2005; WEIBEL and TAYLOR 1988). The ability to visualise airways also reflects the choice of appropriate window settings. These window settings have a marked effect on the apparent size of structures and inappropriate window settings can alter the thickness of the bronchial wall (WEBB et al. 1984). No absolute

window settings can be recommended because of variation between CT machines and individual preferences; however, for diagnostic purposes consistent window settings from patient to patient are advisable and a window centre between –300 and –950 Hounsfield Units (HU) with corresponding window widths between 1,000 and 1,500 HU have been recommended (BANKIER et al. 1996; GRENIER et al. 1993; KANG et al. 1995; SENETERRE et al. 1994).

Although expiration has an important effect on the diameter of the trachea – the anteroposterior diameter can decrease up to 32% between deep inspiration and deep expiration due to the invagination of the posterior tracheal membrane – the diameter of the main and lobar bronchi appears only slightly reduced on full expiration CT scans (STERN et al. 1993).



The presence of visible bronchial structures in the lung periphery (within 2–3 cm of the chest wall) signifies pathologic bronchial wall thickening or ectasia of the small airways.



### 2.4.2

#### Secondary Pulmonary Lobule

Although the identification of secondary pulmonary lobules in normal patients may be difficult with CT, some features that help to identify this anatomical structure are often present. A few septa can be visible in the lung periphery in normal subjects, mostly anteriorly and along the mediastinal pleural surfaces (ABERLE et al. 1988; ZERHOUNI 1989). The location of the interlobular septa can also often be inferred by locating septal pulmonary vein branches. They present as linear, arcuate or branching structures about 5–10 mm from the centrilobular arteriole. This centrilobular arteriole presents as a dot-like, linear or branching opacity within the centre of the lobule or for lobules abutting the pleura at about 1 cm from the pleural surface. Some smaller intralobular vascular branches may be visible between the septa and the centrilobular arteriole, again presenting as small dots or branching lines, but this time about 3–5 mm from the septa (Fig. 2.8).

### 2.4.3

#### Lung Parenchyma

The density of the lung parenchyma should be of greater opacity than air. This density is determined by three components: lung tissue, blood in small vessels beyond the resolution of CT and air (Fig. 2.9). These components are not homogeneously distributed over the lung and the relative proportion is continuously changing in function of normal physiological events. Lung density decreases when lung volume is increased (ROBINSON and KREEL 1979). Although seen in all lung zones, this decrease is not uniform. Due to gravitational effects, lung density is higher in the dependent areas compared to the non-dependent areas (Fig. 2.10). This density difference is similar in both lungs and throughout the lungs. However, this density gradient is strongly affected by lung volume. There is a progressive decrease in this gradient with increasing lung volume, and the density difference between dependent and nondependent regions becomes very small near total lung capacity. This decrease in density gradient is mainly caused by the more important density decrease in the dependent areas compared to the nondependent areas (McCULLOUGH 1983; MILLAR and DENISON 1989; ROSENBLUM et al. 1978, 1980; VERSCHAKELN et al. 1993; WANDTKE et al. 1986; WEBB et al. 1993;

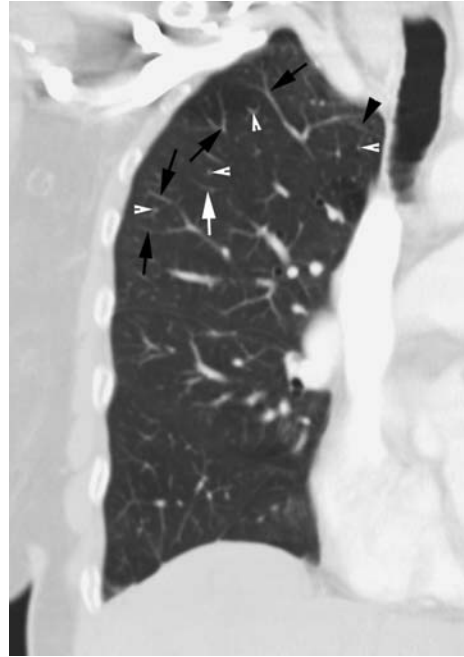


Fig. 2.8. CT of the normal lung (coronal reconstruction). Interlobular septa can sometimes be recognised anteriorly and along the mediastinal surfaces (arrowhead) but can more often be inferred by locating septal pulmonary vein branches (arrows) presenting as linear, arcuate or branching structures approximately 5–10 mm from the centrilobar arteriole (white arrowheads)

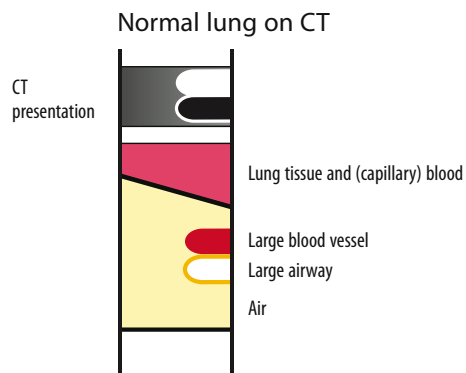
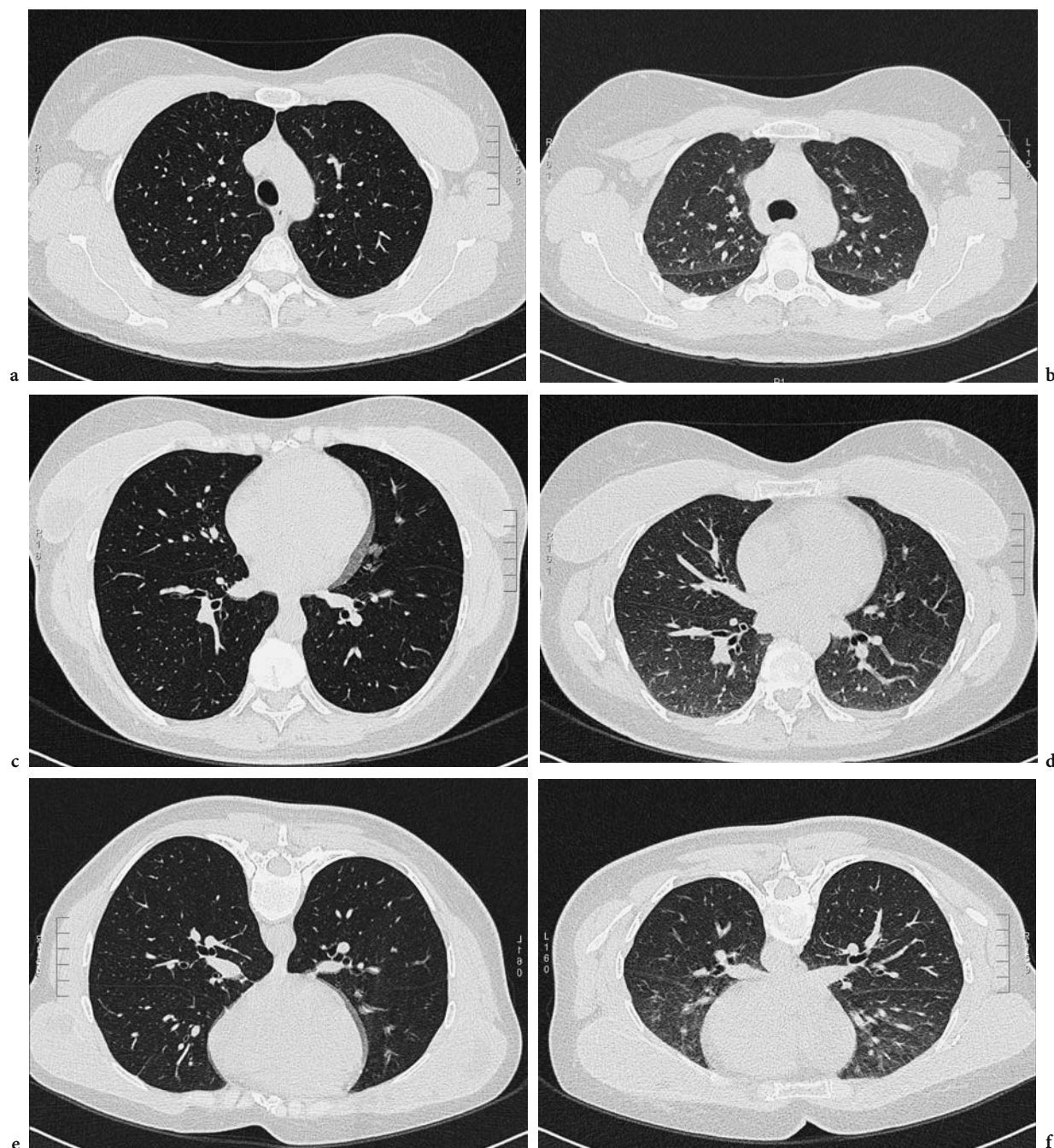


Fig. 2.9. The density of the lung as seen on a CT scan is determined by three components: lung tissue, blood in the small vessels beyond the resolution of CT and air. The relative proportion of these components is continuously changing as a function of normal physiological events

WEGENER et al. 1978). Furthermore, the expiratory lung attenuation increase in dependent lung regions is greater in the lower lung zones than in the middle and upper zones, probably due to greater diaphragmatic movement or greater basal lung volume (WEBB et al. 1993).



**Fig. 2.10a–f.** HRCT of the normal lung at upper and middle levels in supine and at lower level in prone body position (a,c,e, suspended deep inspiration; b,d,f, same levels, suspended deep expiration). Note the density gradient between the dependent and the nondependent lung, which is larger on expiratory scans than on inspiratory scans

In many normal subjects, one or more areas of air-trapping are seen on expiratory scans (Fig. 2.11). In these areas, lung does not increase as much in attenuation as expected and as seen in the surrounding normal areas and appears relatively lucent. This

relative lucency is most typically seen in the superior segments of the lower lobes, posterior to the major fissures, and in the anterior part of the middle lobe and lingua. Often, however, only individual pulmonary lobules are involved, particularly in the lower



**Fig. 2.11.** In many healthy subjects, one or more areas of air-trapping can be seen on expiratory scans, particularly in the lower lobes. Usually only one or a few lobules are involved (arrows)

lobes (LEE et al. 2000; WEBB et al. 1993). Focal areas of air-trapping are seen in up to 75% of asymptomatic subjects, especially in older patients (CHEN et al. 1998; LEE et al. 2000) and in smokers or ex-smokers (VERSCHAKELEN et al. 1998).

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# How to Approach CT of the Lung?

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## 3.1 Introduction

Generally the diagnosis of lung disease on a chest CT is based on three elements (Fig. 3.1):

- Recognition of the appearance pattern of disease, i.e. classifying the abnormalities in a category that is based on their appearance
- Determination of location and distribution of the abnormalities in the lung: the distribution pattern
- Careful analysis of the patient data that are available at the time the CT scan is performed

In a first step the reader should try to recognise the appearance pattern of the lung changes because recognising this pattern makes it possible to develop a first and appropriate differential diagnosis list, including the major categories of disease that might lead to this identified pattern.

In a second step this list should be refined by trying to determine the exact location of these abnormalities. The location of abnormalities should be as precise as possible and is performed by deciding whether these abnormalities are focal or diffuse, predominantly peripheral or central, in the upper, middle or lower parts of the lung, whether the air-spaces or the interstitium are affected and if disease seems to be distributed along the blood vessels, the bronchi or the lymphatics. Combining the appearance pattern and the distribution pattern of the abnormalities can give detailed macroscopic and sub-macroscopic insight into how the lung is affected by the disease and usually further reduces the differential diagnosis list and sometimes even allows making a specific diagnosis.

In a third step, a careful analysis of the patient data that are available is necessary and includes first the study of additional radiological information that is available on this and on previous radiological exams. Examining the present CT scan for other than lung changes can indeed be very helpful to further narrow the differential diagnosis. For example, the simultaneous detection of osteolytic lesions in the ribs and nodules in the lung could suggest metastatic disease. In addition, the examination of serial CT examinations, when available, is very helpful when, for example, examining lesion growth. It can, however, also be interesting to wait for follow-up images before deciding on the diagnosis. In an intensive care patient, when airspace opacities disappear rapidly after the administration of diuretics, a different diagnosis is suggested than when these opacities would remain unchanged or increase in size. Careful analysis of the patient data that are available also includes the correlation with clinical, and pathological, and laboratory data. The knowledge that a patient is immunocompromised will often change the differential diagnosis list.

Although a stepwise analysis of these three elements can result in a diagnosis or a narrow differential diagnosis list, it is often not possible to make

a definitive diagnosis because one or more of the elements discussed are unclear or missing: patterns can overlap and can change over time, disease can show an aberrant localisation and distribution, additional findings can be misleading, previous examinations can be missing or clinical history may be non-specific. Nevertheless, even if a diagnosis cannot be made it should be possible to suggest additional (imaging or other) procedures that may lead to the precise diagnosis.

Finally, it should be emphasised that checking the quality of the examination is very important. Incorrect positioning of the patient, insufficient image collimation, the presence of life-supporting devices and especially incorrect exposure parameters are often responsible for a reduction in image quality and for a possible misinterpretation of the CT findings.

### 3.2

#### Analysis of Patient Data

More than in any other part of the chest, the abnormalities seen in the lung on a CT should be carefully correlated with observations made on other radiological examinations and with all the relevant clinical data that are available at the time of the CT examination. Particularly the group of the diffuse and idiopathic interstitial lung diseases is often very difficult to diagnose when the interpretation is only based on the CT presentation. Ideally cooperation should be established between the clinician who is responsible for the patient, the radiologist and, when pathological information is present or probably required, the pathologist. Especially the radiologist and the pathologist play a complemen-

tary role. While the pathologist has a microscopic view on a very small part of the lung, the radiologist has a macroscopic and submacroscopic view on the entire lung. That is why, as mentioned earlier, it is mandatory for the radiologist to understand why abnormalities appear as they do and where they likely are located both at a macroscopic and at a submacroscopic level. Only then is a fruitful discussion possible.

### 3.3

#### Appearance Pattern of Disease

Generally, CT findings can be classified into four large categories based on their appearance:

- Abnormalities associated with an increase in lung opacity, i.e. increased lung attenuation.
- Abnormalities associated with a decrease in lung opacity, i.e. decreased lung attenuation.
- Abnormalities presenting as nodular opacities.
- Abnormalities presenting as linear opacities.

#### 3.3.1

##### Increased Lung Attenuation

Generally, the increased lung attenuation pattern is caused by an increase in density of the lung parenchyma. As mentioned in Chap. 2, the normal lung density on CT is slightly higher than air and is determined by three components: lung tissue, blood in small vessels beyond the resolution of CT and air. Lung opacity will increase

- When the amount of lung tissue increases or when this tissue becomes denser or larger in size
- When the amount of blood in the small vessels

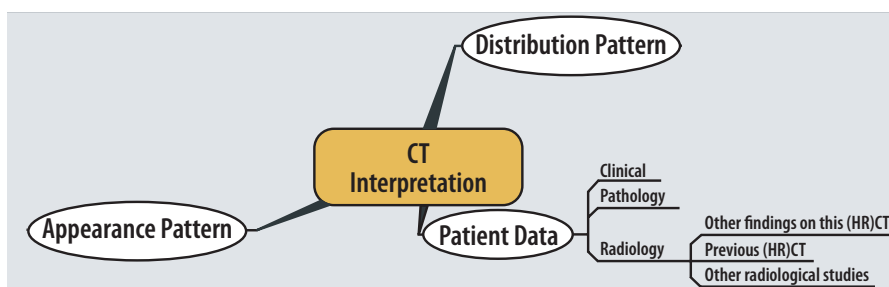


Fig. 3.1. Three basic elements on which diagnosis of lung disease with CT is based

increases, which is usually associated with an expansion of these vessels

- When the relative amount of air decreases, which can be the result of lung volume loss or of replacement of air in the airspaces by fluid and/or cells

The increase in lung attenuation is often the result of two or more of these processes. Knowing these different mechanisms that cause increased lung attenuation, one can expect that the lung architecture as observed within the resolution of CT scan remains more or less intact. Indeed, although disease can of course also affect the large and individually visible bronchovascular structures they are often intact and their arborisation seems normal. Depending on the degree of lung involvement two types of increased lung opacity can be described:

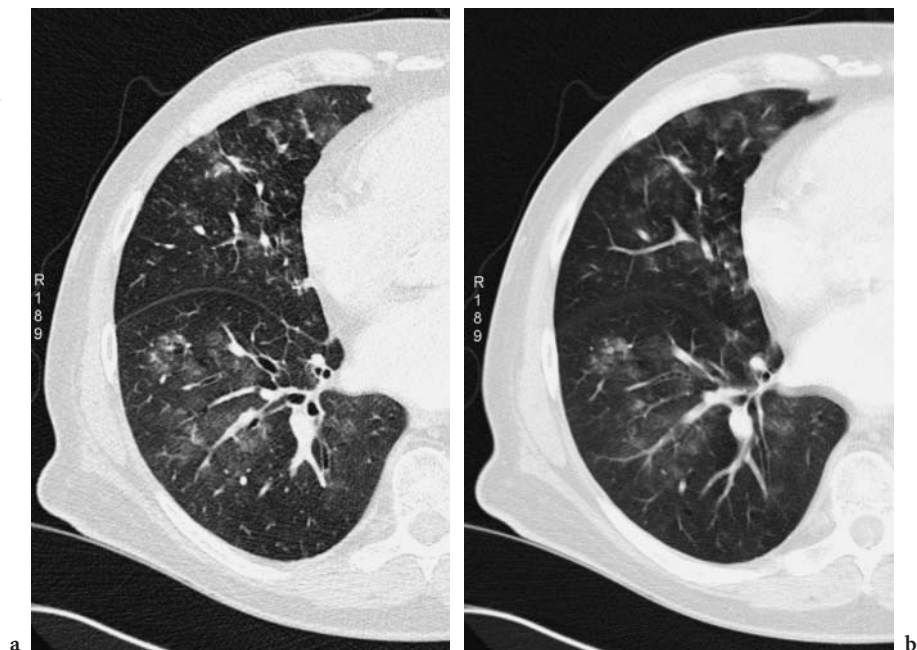
- Ground-glass opacity or ground-glass attenuation when involvement is mild
- Consolidation when involvement is more advanced

The term “ground-glass opacity” or “ground-glass attenuation” is used to describe a hazy increase in lung opacity with preservation of the bronchial and vascular markings (AUSTIN et al.

1996; TUDDENHAM 1984; WEBB et al. 1993) (Fig. 3.2). Ground-glass attenuation can be nodular, focal, regional, multifocal or diffuse. It can be homogenous and heterogeneous and can have sharp or blurred margins. It is important to emphasise that the presence of ground-glass opacity does not necessarily indicate pathology. Physiologic ground-glass attenuation can be seen in the dependent lung areas and in this case is caused by a gravity-related increase in perfusion and decrease in the amount of intra-alveolar air (Fig. 2.10). Ground-glass attenuation is also a normal finding on the expiratory CT scans when the amount of air in relation to tissue and blood decreases (Fig. 2.10).

Lung consolidation, on the other hand, is always a pathologic finding and this term is used to describe an increase in pulmonary parenchymal attenuation that obscures the margins of the vessels and airways (AUSTIN et al. 1996; TUDDENHAM 1984; WEBB et al. 1993) (Fig. 3.3). Although the margins of the airways are obscured, the lumen may be visible when it contains air, typically causing an air-bronchogram. Also, consolidation can be nodular, focal, regional, multifocal or diffuse. It can be homogenous and heterogeneous and can have sharp or blurred margins. A sharp border often results from an adjacent normal anatomic structure such as a lung fissure.

**Fig. 3.2a,b.** Thin-slice (a) and standard CT (b) of the right lung in a patient with a pulmonary infection. The patchy areas of ground-glass opacity are most pronounced in the lower lobe. Note the hazy increase in lung opacity with preservation of the bronchial and vascular markings





**Fig. 3.3a,b.** CT of the right lung (a: mediastinal and b: lung window-center settings). Sharply defined area of lung consolidation. The increased pulmonary density obscures the vessels and the margins of the airways. The lumen of some airways still contain air and these airways become visible as an air-bronchogram

Depending on the degree of involvement, two types of increased lung attenuation can be described:

- Ground-glass opacity or ground-glass attenuation when involvement is mild
- Consolidation when involvement is more advanced

### 3.3.2

#### Decreased Lung Attenuation

When compared with increased lung attenuation, decreased lung attenuation is in part caused by opposite phenomena. An abnormal increase in the amount of air, an abnormal decrease in the intravascular blood volume and, as a result, an abnormal calibre of the vessels that are beyond the resolution of CT, but also tissue destruction and tissue loss are responsible for a decrease in lung attenuation. A decrease in attenuation of the lung parenchyma is always pathologic but does not necessarily indicate that irreversible lung destruction is present. Decreased blood flow or hypoperfusion in an area of the lung results in a reduction in the amount of

blood in the small vessels that are perfusing this area and a reduction in the size of these vessels (Fig. 3.4). This causes a decrease in attenuation of the X-rays in that area and hence an area of decreased lung attenuation. This hypoperfusion can be caused by direct obstruction of the vessels or can be the result of a vasoconstriction secondary to bronchiolar narrowing. Areas of hypoperfusion can be focal or widespread and can be part of the mosaic perfusion, which is defined as a patchwork of regions of varied attenuation, interpreted as secondary to regional differences in perfusion (AUSTIN et al. 1996). It reflects decreased perfusion in lung area and flow redistribution to normal surrounding areas (Fig. 3.5).

A relative increase in the amount of air in the air-spaces will decrease the lung opacity, but also does not necessarily indicate destruction of lung or tissue loss. Such an increase in the amount of air is seen in air-trapping, which is defined as a retention of excess gas (air) in all or part of the lung, especially during expiration, either as a result of complete or partial airway obstruction or as a result of local abnormalities in pulmonary compliance (AUSTIN et al. 1996) (Fig. 3.6).

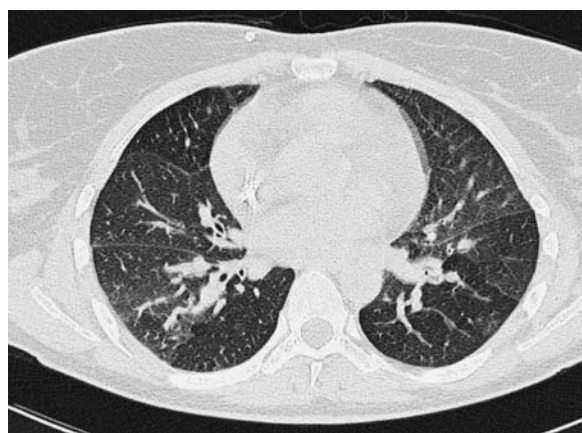
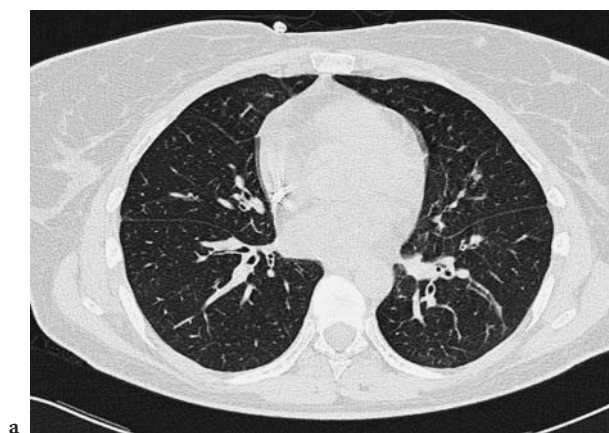
It is obvious that the lung attenuation decreases when lung tissue is destroyed and loss of lung tissue occurs, because the relationship between tissue



**Fig. 3.4.** CT of the lung coronal reconstruction. Hypoperfusion in the left and to a smaller degree in the right lower lobe is responsible for a decrease in lung attenuation. Notice that also the larger vessels have a smaller calibre than normal. The signs of large airway involvement (bronchial wall thickening and bronchial dilatation) suggest that the hypoperfusion is secondary to bronchiolar narrowing

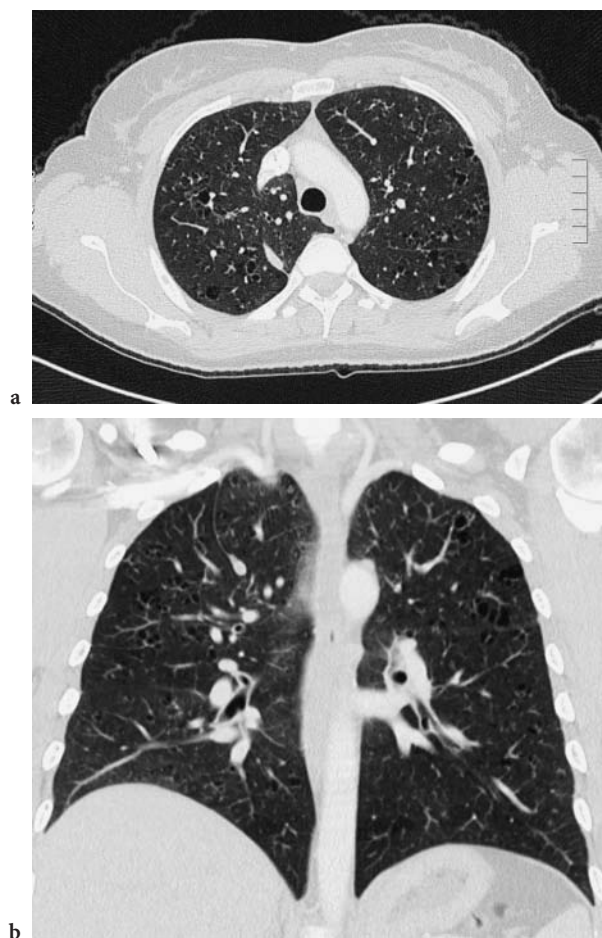


**Fig. 3.5.** CT of the lung coronal reconstruction. Mosaic perfusion in both lungs secondary to recurrent pulmonary embolism and reflecting decreased perfusion in some lung areas and flow redistribution to the normal surrounding areas. Note the difference in vessel calibre when areas of increased and decreased attenuation are compared (*arrows*). This difference in calibre is absent when inhomogeneous lung attenuation is caused by a patchy distribution of ground-glass opacity (Fig. 3.2)



**Fig. 3.6a,b.** CT at end inspiration (a) and at end expiration (b). Multiple large areas of air-trapping are seen in both lungs

and air is disturbed and air becomes the dominant component. However, a concomitant increase in lung tissue or blood flow could normalise the overall lung density. Lung destruction can be cystic or cyst-like. Cysts are low-density thin-walled areas that are well defined and circumscribed and that have a cellular wall (Fig. 3.7). Cyst-like areas of decreased lung attenuation develop because necrosis occurs in pre-existing nodules or nodular opacities. However, lung destruction and loss of lung tissue is most frequently the result of pulmonary emphysema. Pulmonary emphysema is defined as a condition of the lung characterised by permanent, abnormal enlargement of airspaces distal to the terminal bronchiole, accompanied by the destruc-



**Fig. 3.7a,b.** Cystic lung destruction as a cause of decreased lung density. Multiple cystic lesions in both lungs in a patient with Langerhans cell histiocytosis



**Fig. 3.8a,b.** Emphysematous lung destruction as a cause of decreased lung density. Both small (centrilobular emphysema; arrowheads) and large( confluent centrilobular emphysema; arrows) areas of lung destruction are seen in both lungs

tion of their walls (Fig. 3.8). The classification of emphysema is based on the anatomic distribution of these areas of lung destruction in the lung and on their relation to the different parts of the secondary pulmonary lobule.

Generally four causes of decreased lung attenuation can be found:

- Hypoperfusion
- Air-trapping
- Cystic and cyst-like lesions
- Pulmonary emphysema

### 3.3.3 Nodular Pattern

The nodular pattern (Fig. 3.9) is characterised by the presence of multiple nodular opacities with a maximum diameter of 3 cm. A nodule with a diameter less than 1 cm can be defined as a small nodule, whereas a nodule larger than 1 cm is often called a large nodule (GRENIER et al. 1991). The term “micronodule” usually refers to nodules no larger than 7 mm in diameter (AUSTIN et al. 1996). The CT assessment of the nodular pattern is based on:

- Their size (small or large)
- Their appearance (well-defined or ill-defined)
- Their attenuation (soft tissue or ground-glass density)
- Their distribution [(peri)lymphatic, centrilobular, at random]

The CT assessment of the nodular pattern is based on the study of their:

- Size
- Appearance
- Attenuation
- Distribution

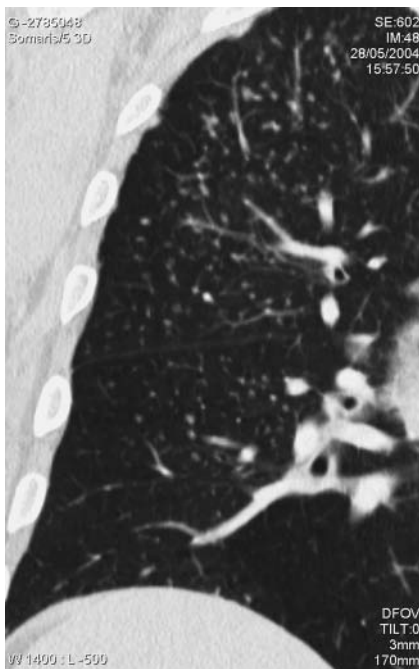
### 3.3.4 Linear Pattern

The linear pattern is characterised by the presence of multiple lines. Since these lines very often cross one another, the term “reticular pattern” is also used. However, this netlike appearance needs not be present, while the number of lines can also be limited. In this situation, the term “linear opacity” is preferred. The differential diagnosis of linear opacities in the lung is predominantly based on the identification of their location and on the study of their appearance (smooth, irregular).

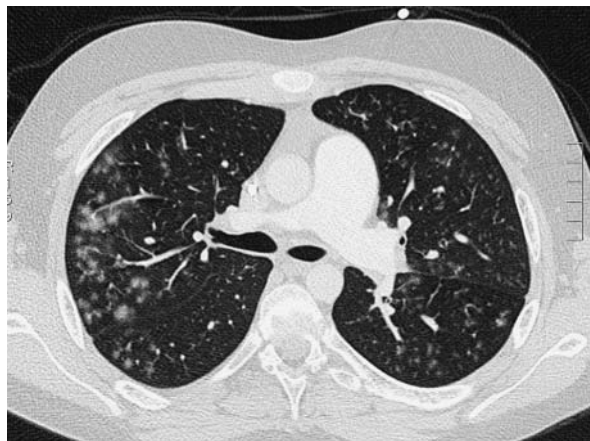
Linear opacities can develop (Fig. 3.10):

- When the interstitium is thickened because of infiltration by cells, fluid or other material
- When lymphatics are involved and/or when (peri)lymphatic disease develops
- When blood vessels increase in calibre
- When airway walls are thickened and/or when their lumen is filled with cells, fluid or other material

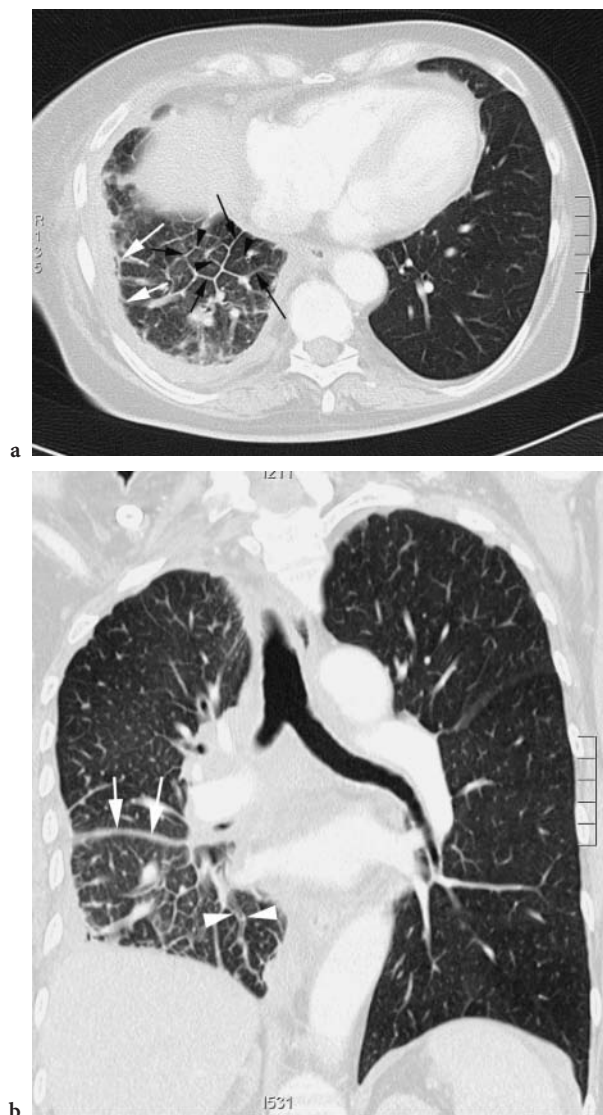
Linear and reticular opacities may be manifested by thickening of the peribronchovascular tissue, by thickening of the subpleural tissue, by thickening of the interlobular septa (septal lines), by intralobular interstitial thickening (intralobular lines), by involvement of the intralobular lymphatics, bronchioles and vascular structures (intralobular lines)



**Fig. 3.9. a** Multiple well-defined nodular opacities with soft tissue density most pronounced in the upper area of the right lung caused by coal workers pneumoconiosis. **b** Multiple ill-defined nodular opacities, some with soft tissue and others with ground-glass density, in a patient with mycoplasma pneumonia







**Fig. 3.10a,b.** Both on the axial (a) and on the coronal slice (b), multiple linear opacities are seen in the right lower lobe. A number of these lines cross each other, creating a reticular pattern. Some lines can be identified as septal lines (*black arrows*), some are intralobular lines (*black arrowheads*), while some are caused by the thickening of the subpleural (*white arrows*) and peribronchovascular interstitium (*white arrowheads*)

and by lines that are located in the lung parenchyma and caused by atelectasis and fibrosis (parenchymal bands, irregular linear opacities, and when parallel with the pleural surface, subpleural lines).

As can be expected from this list of manifestations of linear opacities, the identification of the relationship of the linear opacity and the anatomy of the secondary pulmonary lobule will be important in the differential diagnosis.

#### Linear opacities can develop:

- When the interstitium is thickened
- When lymphatics are involved
- When blood vessels and airways are involved
- When lung atelectasis or fibrosis occurs

### 3.3.5

#### Combination of Patterns

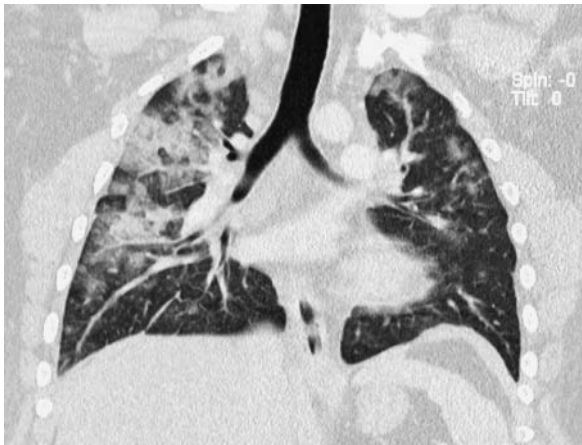
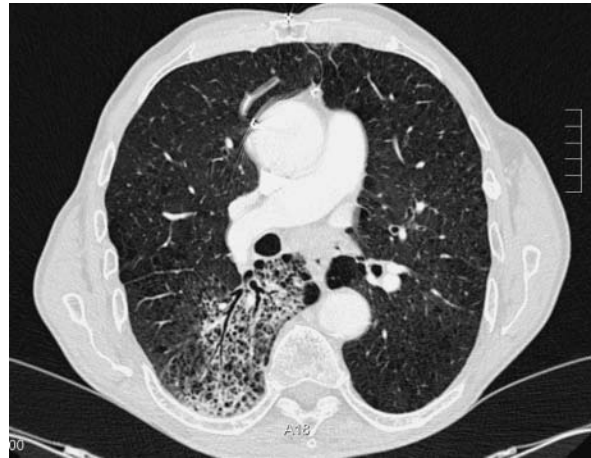
In many cases a combination of two and even more patterns is seen, a phenomenon that often complicates the interpretation of the abnormalities. A mixture of patterns can be caused by a new disease that is superimposed on an already existing lung disease. A typical example is the patient with pulmonary emphysema who develops new disease. It can be expected that in those areas where emphysema is present this new disease can have a totally different appearance pattern than it would have without the presence of pulmonary emphysema (Fig. 3.11). The challenge is to separate the two patterns and to determine their characteristics. One should try to determine the predominant pattern and, when possible, define which pattern has most recently developed. An important resource is of course, when available, a previous CT examination or a chest radiograph.

However, many diseases show two or more patterns at the same time. Lung infection is a typical example because ground-glass opacity, consolidation and centrilobular branching lines (Fig. 3.12) are often seen together.

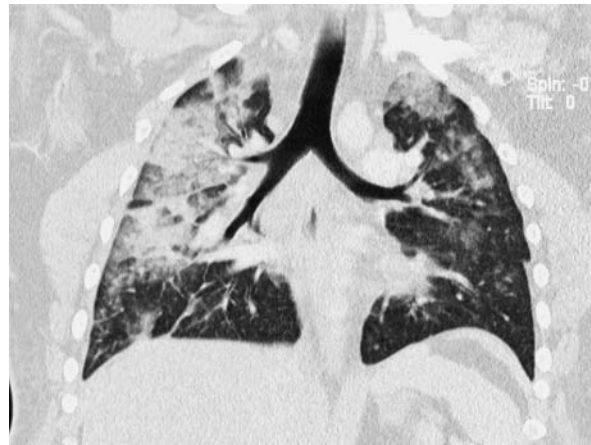
An appearance pattern can also change during the course of the disease and this change can be normal or abnormal. During the transition from one pattern to another two or more patterns can be present simultaneously.

Fortunately, the simultaneous presence of two or more patterns can create mixed patterns that have their own differential diagnosis list. The crazy paving pattern and the honeycombing pattern are two examples. Crazy paving develops when a superposition of the linear pattern on the ground-glass pattern occurs (JONKOH et al. 1999) (Fig. 3.13). Honeycombing combines linear opacities, cystic changes and lung distortion (GENEREUX 1975; PRIMACK et al. 1993) (Fig. 3.14).

**Fig. 3.11.** Pulmonary infection in an emphysematous lung. The combination of increased lung attenuation due to infection and decreased attenuation as seen in lung emphysema may complicate the interpretation of the CT features



a



b

**Fig. 3.12a,b.** In this patient with overwhelming pneumonia, areas of ground-glass opacity and lung consolidation are seen together with ill-defined nodules and linear opacities caused by septal thickening and thickening of the bronchial walls



**Fig. 3.13.** The combination of ground-glass opacity and intra- and interlobular lines creates the crazy-paving pattern



**Fig. 3.14.** Honeycombing combines linear opacities and cystic lung changes (*arrows*)

## 3.4

**Localisation and Distribution of Disease: Distribution Pattern**

The third element on which the CT interpretation of lung diseases is based is the study of the distribution pattern and hence of the localisation of the disease. In order to be able to use disease distribution as a tool to make the diagnosis it is of course mandatory to be familiar with the distribution pattern of that specific disease.

Basically, in a first step it is important to determine:

- Whether the disease is predominantly located in the upper lung or in the lower lung or that the disease is more or less equally distributed in both lungs
- Whether the abnormalities are predominantly located in the lung periphery or more axially surrounding the large bronchovascular structures or perhaps somewhere in between
- Whether the abnormalities have a preference for the dependent areas of the lung or not

Table 3.1 shows the regional distribution of the most frequently occurring lung diseases.

In a second step, an attempt should be made to further refine this localisation by trying to relate the abnormalities to the anatomy of the lung and especially the anatomy of the secondary pulmonary lobule. Where is pathology exactly located: in or surrounding the blood vessels [(peri-)vascular], in or surrounding the large airways [(peri-)bronchial], immediately under the pleura (subpleural), in the interlobular septa; in the central part of the secondary pulmonary lobule; or somewhere in between? As was discussed in Chap. 2, given the specific location of the pulmonary interstitium, pulmonary lymphatics, airways, arterioles and veins in relation to the different parts of the secondary pulmonary lobule, one can often decide whether the disease is distributed through or along the airways, the arteries, the veins or the lymphatics and whether the disease seems to involve predominantly the interstitium or the airspace. Thus it is often possible to further refine the diagnosis or reduce the differential diagnosis list.

Table 3.1. Regional distribution of lung diseases

**Upper lung versus lower lung versus diffuse distribution**

*Upper:* Langerhans cell histiocytosis, sarcoidosis, silicosis and coal workers' pneumoconiosis, tuberculosis, respiratory bronchiolitis, cystic fibrosis, chronic eosinophilic pneumonia, centrilobular emphysema, paraseptal emphysema

*Lower:* oedema, usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), desquamative interstitial pneumonia (DIP), lipoid pneumonia, organising pneumonia, haematogenous metastases, alveolar haemorrhage, panlobular emphysema

*Diffuse:* hypersensitivity pneumonitis, lymphangioleiomyomatosis, diffuse pneumonia, lymphangitic spread of tumour, haematogenous metastases, sarcoidosis

**Central lung versus peripheral lung**

*Central:* sarcoidosis, silicosis and coal workers' pneumoconiosis, lymphangitic spread of tumour, alveolar proteinosis, large airways disease

*Peripheral:* usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), chronic eosinophilic pneumonia, organising pneumonia, acute interstitial pneumonia (AIP), desquamative interstitial pneumonia (DIP), hypersensitivity pneumonitis, haematogenous metastases, septic emboli, pulmonary embolism, small airways disease

**Posterior versus anterior lung**

*Posterior:* pulmonary oedema, adult respiratory distress syndrome (ARDS) usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), silicosis and coal workers' pneumoconiosis, sarcoidosis, hypersensitivity pneumonitis, lipoid pneumonia

*Anterior:* post-adult respiratory distress (ARDS) fibrosis

**Can be unilateral or asymmetric**

Pneumonia, lymphangitic spread of tumor, sarcoidosis

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# Increased Lung Attenuation

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## 4.1

### Introduction

Increased lung attenuation patterns develop when the density of the lung parenchyma increases. As mentioned in Chapter 2, the normal lung density on CT is slightly higher than air and is determined by the balance between air in the airspaces and in the small airways, on one hand, and the soft tissue structures that have a higher density than air but that are as such not individually visible on the other hand. These soft tissue structures include the interstitial lung tissues, the wall of the alveoli, small airways and capillaries and the blood in these capillaries.

Increased lung opacity will occur when the amount of air in the airspaces and in the lumen

of the airways decreases and when the soft tissue structures increase in size and/or amount, two phenomena that often occur simultaneously (ENGELER et al. 1993; LEUNG et al. 1993; MÜLLER et al. 1987; WEBB 1989; WELLS et al. 1992) (Fig. 4.1).

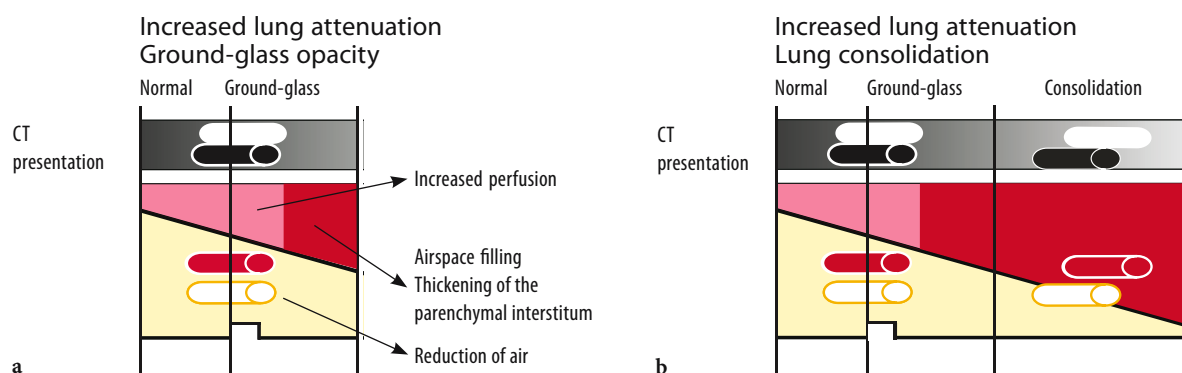
A decrease in the amount of air can be the result of (1) a reduction in the volume (expansion) of the airspaces and to a lesser degree the volume of the small airways, and (2) a partial or total replacement of the air in the airspaces by fluid or cells. These changes are often simultaneously present.

An increase in size and/or volume of the soft tissues – and hence an increased lung opacity – can be the result of (1) an increase in the calibre of the capillaries resulting from an increase in blood flow and blood volume in these vessels, and (2) a thickening of the interstitial tissues and of the alveolar wall. Also, an abnormal thickening of the wall of the small blood vessels and of the small airways may to some degree contribute to an increase in lung opacity (Fig. 4.1).

The degree of parenchymal opacification on CT depends on the amount of reduction of air in the airspaces and on the amount of increase in size and/or volume of the soft tissues (Fig. 4.1). When the changes are limited, the increased lung opacity is described as being a “ground-glass opacity” referring to the presence on CT of a hazy increase in lung opacity that does not obscure the underlying vessels. When more pronounced, i.e. when the vessels are obscured, the term “lung consolidation” or “consolidation” is used.

Some diseases present with one or more areas of “increased lung attenuation that have a density that is greater than soft tissue density.” This high density is usually related to the development of calcifications within existing lesions but can also be the result of deposition of calcium within the lung parenchyma or rarely of diffuse or multifocal pulmonary ossification (GEVENOIS et al. 1994; IM et al. 1993; JOHKOH et al. 1993; REMY-JARDIN et al. 1990a, 1990b).





**Fig. 4.1.** **a** Ground-glass opacity can be the result of (1) a decrease in the air in the airspaces, which may result from a reduction of airspace volume and from replacement of air by fluid or cells and (2) an increase in size and/or volume of the soft tissues either by an increase in the blood volume or thickening of the interstitial tissues. **b** Consolidation is usually the result of replacement of air by fluid or cells but can be caused by an extreme thickening of the interstitial tissues

## 4.2

### Types of Increased Lung Attenuation Patterns

#### 4.2.1

##### Ground-Glass Opacity

Ground-glass opacity is defined as a hazy increase in lung density with preservation of airway and vessel margins, i.e. the underlying vessels are not obscured by the increase in lung density while, even though the bronchial walls may be somewhat obscured, the airways remain identifiable (Fig. 4.2). The airways are often better recognised than when no ground-glass opacity is present, and even smaller airways may become visible because the density difference between the air in the airway lumen and the surrounding abnormal lung parenchyma has increased, i.e. the airways appear “too black” (AUSTIN et al. 1996; TUDDENHAM 1984; WEBB et al. 1993a) (Fig. 4.2).

Ground-glass opacity may be diffuse and can even involve the whole lung to an equal degree. In that case, recognition of the pattern can be difficult and this is especially true when the density increase is minimal (Fig. 4.3). In case of doubt, one should look for airways to appear too black, one should compare the lung density with the density in the trachea and main bronchi and, when an expiratory scan is performed, one should study the lung density on these expiratory CT slices. Normally the density difference between the lung parenchyma and the air in the trachea and main stem bronchi is minimal and an increase in density difference should alert the observer (Fig. 4.3). The observer should also be alerted

when density increase of the lung parenchyma is more than expected during expiration. In order to be able to recognise these often minimal density changes, the observer should be familiar with the CT window-centre settings and with the display settings that are used and that, in addition, should be kept constant over time. Fortunately, ground-glass opacity usually shows a patchy distribution allowing a confident diagnosis in most cases (Fig. 4.2).

The border between normal lung parenchyma and the areas of ground-glass opacity may be ill defined (Fig. 4.2) but can also be sharp (Fig. 4.4).

In some diseases, ground-glass opacity may have a lobular distribution involving a few or several secondary pulmonary lobules but leaving the adjacent lobules unaffected.



**Fig. 4.2.** Patchy distribution of ground-glass opacity in a patient with *Pneumocystis jiroveci* pneumonia. Note that air in small bronchial structures becomes visible because of the high-density difference with the surrounding lung (arrow)



**Fig. 4.3.** Diffuse ground-glass opacity in a patient with hypersensitivity pneumonitis. Note the high-density difference between the air in the trachea and the lung density

In other diseases, ground-glass opacities are located near the centre of the secondary pulmonary lobules and then look like ill-defined nodules (see also Sects. 6.2.1 and 6.3.2 in Chap. 6) (Fig. 4.5).

#### 4.2.1.1

##### **Ground-Glass Opacity Caused by a Reduction of Air in the Airspaces**

##### 4.2.1.1.1

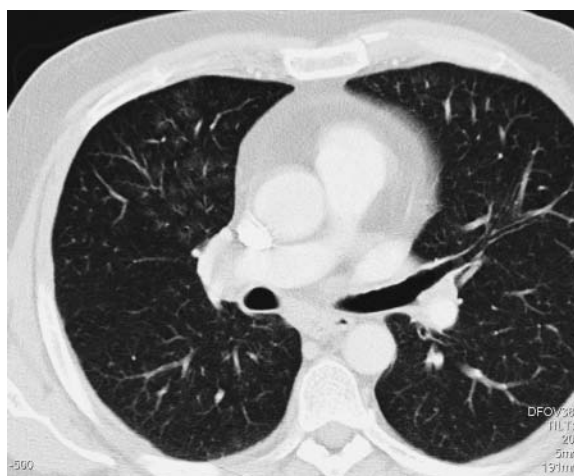
##### **Volume Loss of the Alveoli**

Expiration, as previously explained, is a normal physiological phenomenon that causes volume loss of the alveoli and is responsible for the development of ground-glass opacity (Fig. 2.10). It may mimic the appearance of ground-glass opacity resulting from lung disease. The observer should carefully verify the degree of inspiration, especially when an overall increase in lung density is seen.

Ground-glass opacity is also frequently seen in the dependent lung areas in CT scans performed both at suspended deep inspiration and suspended deep expiration and results from volume loss of the alveoli in these areas. This dependent density can have a thickness of several centimetres and is more pronounced on expiratory scans (ABERLE et al. 1988) (Fig. 2.10). In addition, this increase in density in dependent lung regions is greater in the lower lung zones than in the middle and upper zones, probably due to greater diaphragmatic movement or the more important gravitational effect of the greater basal lung volume (McCULLOUGH 1983;



**Fig. 4.4.** Sharply defined area of ground-glass opacity in the right upper lobe caused by pulmonary haemorrhage. Note the relative high density (although it does not obscure the vessels) and the presence of a faint intralobular reticular pattern



**Fig. 4.5.** Pulmonary haemorrhage in the right middle lobe. Ground-glass opacities are located near the centre of the secondary pulmonary lobules and look like ill-defined nodules

MILLAR and DENISON 1989; ROSENBLUM et al. 1978; ROSENBLUM et al. 1980; VERSCHAKELLEN et al. 1993; WANDTKE et al. 1986; WEBB et al. 1993b; WEGENER et al. 1978). This gravitational effect is also reflected in the frequently seen decrease in lung density in the apical segment of the lower lobes immediately posterior of the major fissure in supine body position (Fig. 2.10). Dependent density should be differentiated from true abnormality. In case of doubt, prone



Fig. 4.6. Decreased expansion of the right lung in a patient with right-sided malignant mesothelioma. Note the density difference between the right and the left lung

scans should be performed on which the dependent density is no longer visible against the posterior chest wall and may appear against the anterior chest wall.

Volume loss of the alveoli may also be the result of pathological changes in the lung and pleura. Fibrotic scarring in the lung and pleural thickening can both restrict lung expansion and can be responsible for the development of ground-glass opacity (Fig. 4.6).

#### 4.2.1.1.2

##### **Replacement of Alveolar Air**

Partial filling of the alveolar spaces by fluid or cells can also be responsible for the development of ground-glass opacity because (especially in early disease) the fluid or cells tend to layer against the alveolar walls (LEUNG et al. 1993; REMY-JARDIN et al. 1993a). Partial filling of the alveolar spaces can be the only cause of ground-glass opacity but very often associated thickening of the interstitium and of the alveolar walls is present. In alveolar proteinosis, respiratory bronchiolitis and respiratory bronchiolitis interstitial lung disease, alveolar haemorrhage and bronchioloalveolar cell carcinoma, the alveolar space is usually the histologic site of predominant involvement (GRUDEN and WEBB 1993; LEUNG et al. 1993; MÜLLER and MILLER 1993; REMY-JARDIN et al. 1993b). This airspace filling process may have preponderance at the periphery of the lobules and acini causing linear opacities (perilobular and intralobular linear pattern) (Fig. 4.7) (see Sects. 7.2.1 and 7.2.2 in Chap. 7) in addition to the ground-

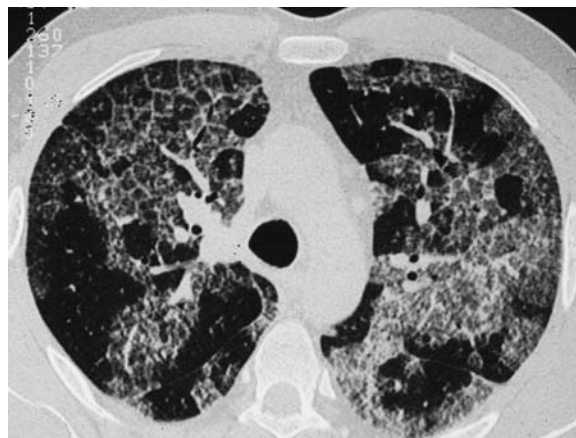


Fig. 4.7. Alveolar proteinosis. Areas of ground-glass opacity are seen in both lungs. These areas have a geographic appearance while an intralobular reticular pattern is superimposed creating the crazy-paving pattern. This reticular pattern is very likely the result of preponderance of the protein and lipid-rich material at the periphery of the lobules and acini together with some septal oedema

glass opacity creating the crazy-paving pattern (see Sect. 4.2.1.5).

#### 4.2.1.2

##### **Ground-Glass Opacity Caused by an Increase in Parenchymal Perfusion**

An increase in perfusion of a lung region results in an increase in capillary blood volume in that area and can be responsible for an increase in lung density. This density increase is more easily recognised when this increase is patchy in distribution,

i.e. when there is mosaic perfusion (LYNCH et al. 1990; MARTI-BONMATI 1989; MURATA et al. 1996; WEBB 1994; WEBB et al. 1993a) (Figs. 4.8 and 5.3). As will be explained in more detail in Sect. 5.2.1 of Chapter 5, mosaic perfusion refers to the presence of areas with increased attenuation (ground-glass opacity) adjacent to areas of decreased attenuation. These areas of decreased attenuation are caused by either narrowing or obstruction of the blood vessels, with reduction of the capillary blood volume in that area or by small airways narrowing with reflex vasoconstriction and again reduced capillary blood volume. The adjacent areas of increased lung attenuation that present as ground-glass opacity are the result of redistribution of blood flow to these normal lung areas (AUSTIN et al. 1996). This mosaic perfusion, which is also called mosaic oligemia and mosaic pattern, should be differentiated from the patchy distribution of ground-glass opacity caused by lung disease (Figs. 4.2 and 5.4). In this cause of the mosaic pattern, the areas of ground-glass opacity are superimposed on normal lung and therefore the terms “mosaic perfusion” and “mosaic oligemia” cannot be used. Differential diagnosis is based on the calibre of the blood vessels, the delineation of the ground-glass opacity and density changes after deep expiration (ARAKAWA et al. 1998; IM et al. 1996) (Table 5.2). The density gradient between nondependent and dependent lung is also in part explained by the gravity-induced increase in capillary blood volume in the dependent areas. Because blood flow is greater in the dependent zones of the lung, the arteries and veins in these areas are larger. The ensuing greater volume of blood accounts for the higher lung density and can, together with the reduced expansion of the airspaces in these areas, be responsible for the development of ground-glass

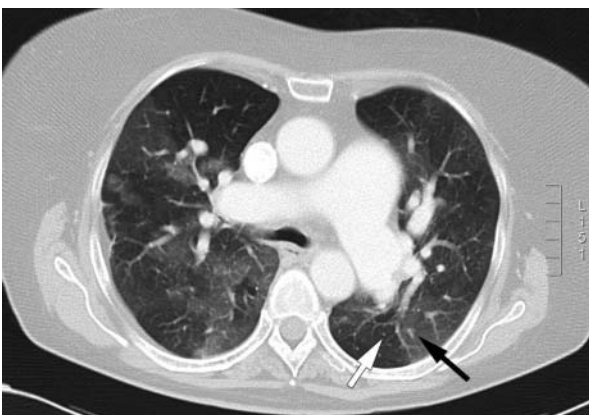
opacity (HOWELL et al. 1961; KANEKO et al. 1966; PERMUTT et al. 1961; VERSCHAKELLEN et al. 1993).

#### 4.2.1.3

##### **Ground-Glass Opacity Caused by Thickening of the Parenchymal Interstitium and of the Alveolar Wall**

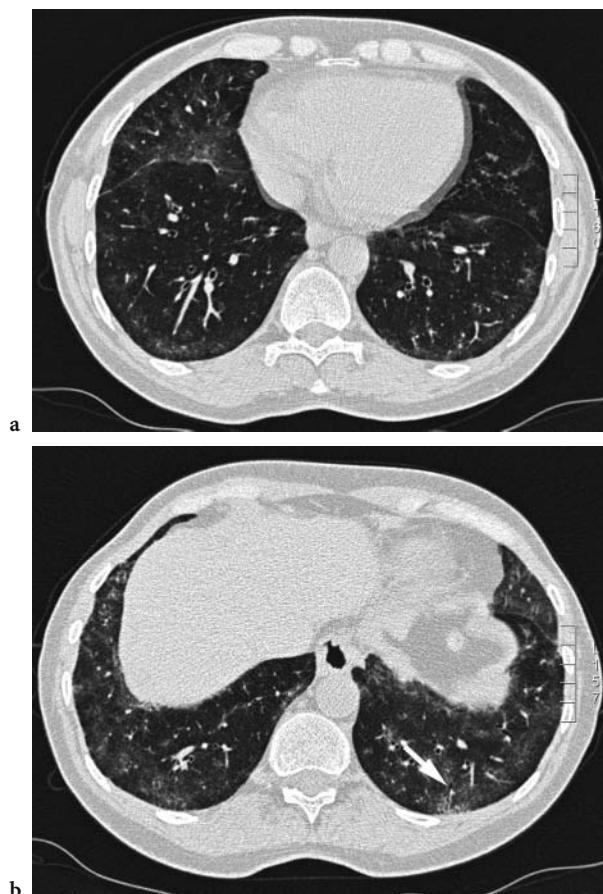
A minimal thickening of the alveolar wall and of the parenchymal interstitium can also cause ground-glass opacity. In many cases, this minimal thickening of the alveolar wall and interstitium results from early alveolar wall and interstitial inflammation or infiltration, and is then very often associated with the presence of an intraalveolar cellular infiltrate that, by filling the airspaces, also enhances the X-ray attenuation (LEUNG et al. 1993; REMY-JARDIN et al. 1993a). All this indicates the likelihood of active disease, especially in a patient with acute symptoms. However, not only in patients with acute symptoms, but also in patients with subacute and chronic symptoms, ground-glass opacity may result from acute inflammation indicating active disease or reactivation of disease. On the other hand, it is very important to realise that ground-glass opacity may also be caused by fibrosis and result from fibrotic thickening of the alveolar wall and interstitium (LEUNG et al. 1993; REMY-JARDIN et al. 1993a). That is the reason why one should be careful to diagnose ground-glass opacity as an active process and make this diagnosis only when there are no associated findings of fibrosis such as traction bronchiectasis or honeycombing and when ground-glass is the predominant finding (REMY-JARDIN et al. 1993a) (Fig. 4.9).

Nevertheless, when a lung biopsy is performed, areas of ground-glass opacity are the best locations to be targeted by the surgeon or bronchoscopist, especially when no signs of fibrosis are present.



**Fig. 4.8.** Mosaic perfusion secondary to recurrent pulmonary embolism. The areas of ground-glass opacity are “normal” lung regions with increased perfusion and increased blood volume. This increase in perfusion is the result of redistribution of blood from the hypoperfused surrounding areas. Note the difference in calibre of the vessels between hyper and hypoperfused lung areas (arrows)



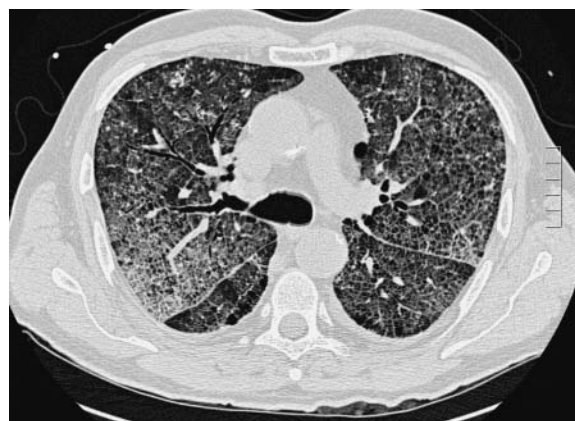


**Fig. 4.9a,b.** Usual interstitial pneumonia in a patient with systemic sclerosis. **a** The dominant pattern is ground-glass opacity, which is located in the dorsal and basal subpleural region of both lungs, suggesting active lung disease. However, at the basal slice (**b**), there is some irregular interstitial thickening together with some bronchial distortion (*arrow*), suggesting the presence of fibrosis in that part of the lung

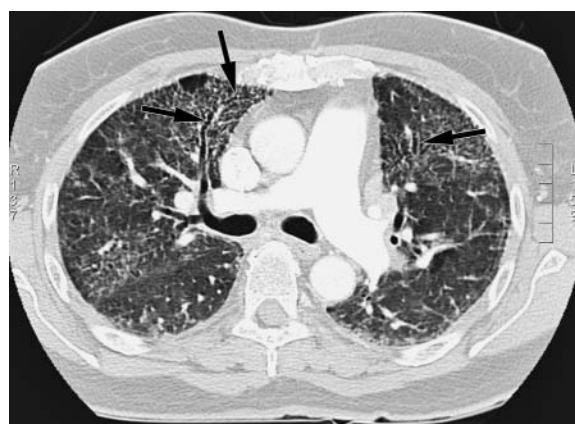
#### 4.2.1.4

##### Acute Versus Subacute or Chronic Disease

From the previous section, it is obvious that both acute and subacute or chronic lung diseases can be responsible for the appearance of ground-glass opacities on a CT of the lungs, and although the presence of traction bronchiectasis and honeycombing can be helpful in suggesting chronic disease as a cause, it is very important, when considering the differential diagnosis of ground-glass opacity, to know whether the patient's symptoms are acute, subacute or chronic. Together with the distribution pattern (Fig. 4.22), this will guide the differential diagnosis (Figs. 4.10 and 4.11). Table 4.1 lists the



**Fig. 4.10.** Acute interstitial pneumonia. Ground-glass opacity is associated with linear opacities, creating a crazy-paving pattern



**Fig. 4.11.** Diffuse ground-glass opacity in a patient with chronic hypersensitivity pneumonitis. Bronchial deformation (*arrows*) indicates pulmonary fibrosis

most frequent causes of ground-glass opacity according to the predominant course of the disease (AKIRA et al. 1992; BERGIN et al. 1990; BESSIS et al. 1992; BRAUNER et al. 1989; CHEON et al. 1996; FRANQUET et al. 1998; GRAHAM et al. 1991; GRUDEN and WEBB 1993; GRUDEN et al. 1997; HOLT et al. 1993; HOMMEYER et al. 1991; IKEZOE et al. 1988, 1990; JOHKOH et al. 1999b; LEUNG et al. 1993; MCGUINNESS et al. 1994; MURCH and CARR 1989; MURDOCH and MÜLLER 1992; PRIMACK et al. 1993; REITTNER et al. 1999; REMY-JARDIN et al. 1993a; SILVER et al. 1989; STORTO et al. 1995; TAN and KUZU 1997).



**Table 4.1.** Differential diagnosis of ground-glass opacity, divided into diseases with generally an acute course and diseases with a subacute or chronic course. Note that the presence of ground-glass opacity in subacute and chronic diseases often indicates active disease in that area, particularly in the absence of clear signs of lung fibrosis

Acute course of disease
<ul style="list-style-type: none"> <li>● Pulmonary infection (bacterial, viral, pneumocystis jiroveci pneumonia, mycoplasma pneumonia)</li> <li>● Pulmonary oedema</li> <li>● Pulmonary haemorrhage</li> <li>● Adult (acute) respiratory distress syndrome [ARDS]</li> <li>● Acute interstitial pneumonia [AIP]</li> <li>● Eosinophilic pneumonia (acute)</li> <li>● Radiation pneumonitis (acute)</li> </ul>
Subacute/chronic course of disease
<ul style="list-style-type: none"> <li>● Hypersensitivity pneumonitis</li> <li>● Smoking related parenchymal lung disease, respiratory bronchiolitis (Respiratory bronchiolitis - interstitial lung disease [RB-ILD], Desquamative interstitial pneumonia [DIP])</li> <li>● Usual interstitial pneumonia [UIP]: idiopathic pulmonary fibrosis [IPF] and disease associated UIP</li> <li>● Nonspecific interstitial pneumonia (NSIP)</li> <li>● Alveolar proteinosis</li> <li>● Lymphocytic interstitial pneumonia [LIP] (Sjögren syndrome, AIDS)</li> <li>● Asbestosis</li> <li>● Vasculitis (Churg-Strauss syndrome)</li> <li>● Eosinophylic pneumonia (chronic)</li> <li>● Organising pneumonia</li> <li>● Bronchioloalveolar carcinoma</li> <li>● Lipoid pneumonia</li> <li>● Sarcoidosis</li> </ul>

#### 4.2.1.5

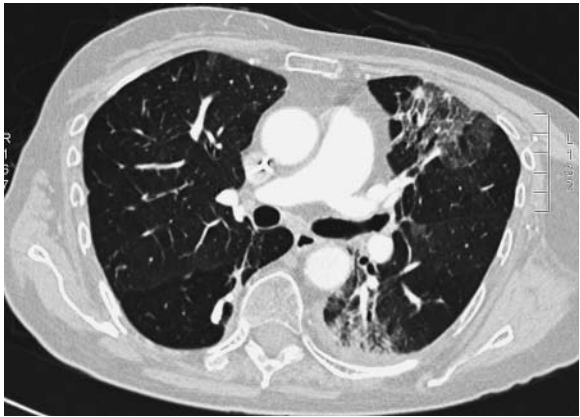
##### Crazy-Paving Pattern

Superposition of a linear pattern on ground-glass opacity results in a pattern that is termed crazy paving (MURCH and CARR 1989) (Fig. 4.10). This pattern was initially described in patients with pulmonary alveolar proteinosis, but is also seen in patients with

other diseases (JOHKO et al. 1999a; MURAYAMA et al. 1999). From previous sections, we can learn that the ground-glass component of the crazy-paving pattern can be the result of a replacement of air in the airspaces and of a thickening of the alveolar wall and the interstitium – and this thickening may even be fibrotic – while the linear component can be caused by a thickening of the interlobular septa (septal lines), a thickening of the intralobular septa and the interstitium (intralobular reticular pattern and intralobular branching lines) and a linear deposition of material within the airspaces at the borders of the acini and the secondary pulmonary lobules (perilobular pattern) (JOHKO et al. 1999a, 1999b) (Fig. 4.12). Consequently, crazy-paving can be the result of diseases that primarily affect the airspaces, diseases that primarily affect the interstitium or diseases that affect both lung compartments (JOHKO et al. 1999a; MURAYAMA et al. 1999). The fact that linear opacities are part of this pattern explains why the crazy-paving pattern is discussed again in Chapter 7 where the linear pattern is explained in detail (see Sects. 7.2.1 and 7.2.2 and Figs. 7.6, 7.10 and 7.25 in Chap. 7). Table 4.2 shows the different causes of the crazy-paving pattern.



- Ground-glass opacity is defined as a hazy increase in lung density with preservation of airway and vessel margins
- Ground-glass opacity occurs when there is a mild decrease in the amount of air in the airspaces and when there is a mild increase in size and/or amount of the soft tissue structures, two phenomena that often occur simultaneously
- Both acute and subacute or chronic lung diseases can be responsible for the appearance of ground-glass opacity, although the presence of traction bronchiectasis and honeycombing suggest chronic disease as a cause
- The crazy-paving pattern is created when ground-glass opacity is associated with the presence of a linear pattern. This linear pattern is caused by thickening of the interlobular septa, thickening of the intralobular septa and interstitium or by an airspace filling process that has preponderance at the periphery of the lobules and acini.



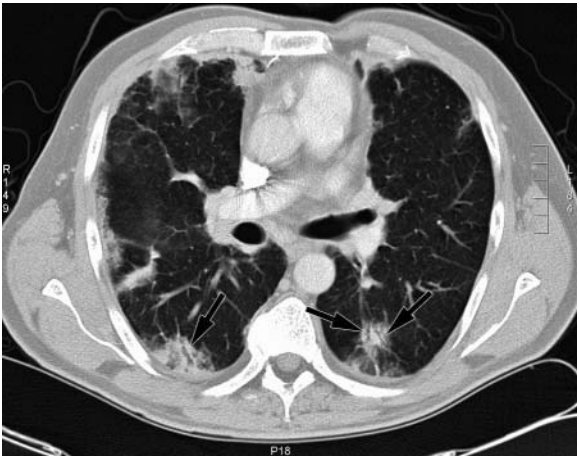
**Fig. 4.12.** Acute radiation pneumonitis in a patient treated for left-sided breast cancer. Areas of ground-glass opacity and consolidation can be seen in the left lung. Note the presence of a faint intralobular reticular pattern in the ground-glass opacity against the anterior chest wall, creating a crazy-paving pattern. Deformation of a bronchial structure also suggests some fibrotic changes

**Table 4.2.** Differential diagnosis of crazy-paving pattern

Acute course of disease
● Pulmonary oedema
● Pulmonary infection (bacterial, viral, <i>Pneumocystis jiroveci</i> pneumonia, mycoplasma pneumonia)
● Pulmonary haemorrhage
● Acute interstitial pneumonia [AIP]
● Adult (acute) respiratory distress syndrome [ARDS]
● Radiation pneumonitis (acute)
● Eosinophilic pneumonia (acute)
Subacute/chronic course of disease
● Usual interstitial pneumonia [UIP]; idiopathic pulmonary fibrosis [IPF] and disease associated UIP
● Nonspecific interstitial pneumonia [NSIP]
● Alveolar proteinosis
● Organising pneumonia
● Vasculitis (Churg-Strauss syndrome)
● Eosinophylic pneumonia (chronic)
● Bronchioloalveolar carcinoma (mucinous)
● Lymphangitic spread of tumour
● Sarcoidosis
● Lipid pneumonia

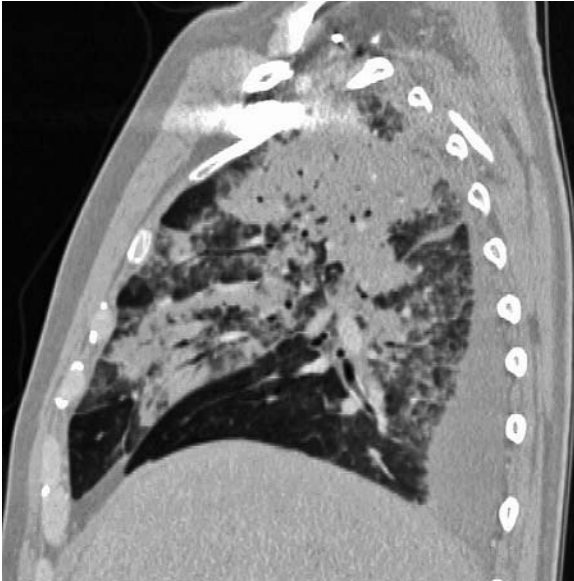
4.2.2  
Lung Consolidation

Consolidation is defined as an increase in lung density with obscuration of the underlying vessels (Figs. 4.1 and 4.13). Although the bronchial walls are also obscured, bronchi can often be recognised as an air bronchogram, i.e. low-density branching tubular structures within the lung consolidation. This air bronchogram is created by the high difference in density between the air in the open bronchi and the dense surrounding airspaces. In this way, bronchi that are normally not seen often become visible (TUDDENHAM 1984; WEBB et al. 1993a). The lung changes that cause lung consolidation are very similar to the lung changes that are responsible for ground-glass opacity: a decrease in the amount of air in the airspaces and thickening of the interstitium. However, the most frequent cause is a decrease in the amount of air in the airspaces, which is by definition the result of replacement of this air by fluid, cells, tissue or other substances (HOMMEYER et al. 1991; NAIDICH et al. 1985; TUDDENHAM 1984). Diseases such as usual interstitial pneumonia (UIP) and sarcoidosis can, however, produce very extensive confluent interstitial abnormalities presenting as areas of lung consolidation on CT (LEUNG et al. 1993; TRAILL et al. 1997) (Fig. 6.4b). The fact that consolidation and ground-glass opacity are in part established in a similar way explains why the differential diagnosis list of diseases that cause lung consolidation overlaps the list of diseases that cause ground-glass opacity.



**Fig. 4.13.** Several subpleural areas of lung consolidation in a patient with eosinophilic pneumonia. Note the air bronchogram (arrows)

Lung consolidation may be focal, multifocal, patchy or diffuse. Often lung consolidation has one or more sharply defined borders because the pathology reaches an anatomic structure such as a fissure (Fig. 4.14). Borders of the lung consolidation that are not adjacent to the fissure may be sharply defined or



**Fig. 4.14.** Large areas of lung consolidation and ground-glass opacity in a patient with overwhelming pneumonia. Part of the lung consolidation is delineated by the major fissure

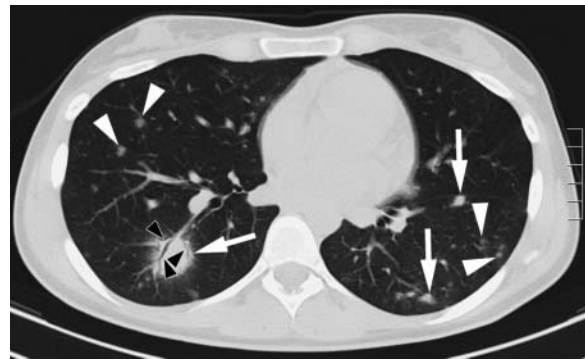


**Fig. 4.15.** Pulmonary infection with lung consolidation and ground-glass opacity. Note the irregular borders of the lung consolidation that is surrounded by ground-glass density

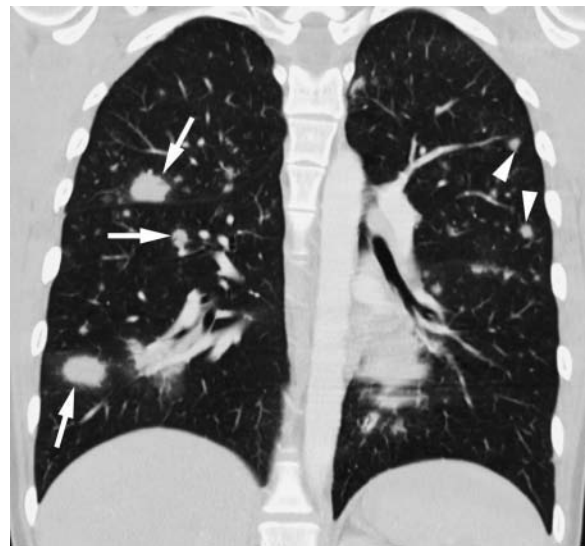
may be irregular and blurred and are then possibly surrounded with ground-glass opacity (Fig. 4.15). When sharply defined, airspace filling by tissue (tumour, granulation tissue) is suggested (Fig. 4.16), when blurred airspace filling by fluid or cells may be the cause (Fig. 4.15).

Similar to ground-glass opacity, to make the differential diagnosis of lung consolidation, it is also very important to know whether the patient's symptoms are acute, subacute or chronic.

Since airspace filling is the most frequent cause of lung consolidation, this pattern is often associated with the presence of centrilobular airspace nodules corresponding with early airspace filling, as is often seen in diseases that show a bronchial distribution (Fig. 4.17) (see Sect. 6.2.1 in Chap. 6).



a



b

**Fig. 4.16a,b.** Consolidation caused by airspace filling with fibroblastic tissue in a patient with organising pneumonia. Sharply defined areas of lung consolidation are seen in both lungs (large arrows). Note the air bronchogram (black arrowheads) and the centrilobular airspace nodules (white arrowheads)



Fig. 4.17. Aspiration. Centrilobular airspace nodules are seen in the right lower lobe. These nodules can merge together and create an area of lung consolidation

Table 4.3 gives an overview of the most frequent causes of lung consolidation and indicates which diseases show an acute course and which diseases usually have a subacute or chronic progress (AKIRA et al. 1992, 1999; BOUCHARDY et al. 1993; BOURGOUIN et al. 1987; BRAUNER et al. 1992; GODWIN et al. 1988; IKEZOE et al. 1988; LEUNG et al. 1993; LIBSHITZ and SHUMAN 1984; MAYO et al. 1989; MOSKOVIC et al. 1990; MÜLLER et al. 1987; NAIDICH et al. 1985; PRIMACK et al. 1993).

Table 4.3. Differential diagnosis of lung consolidation, divided into diseases with a generally acute course or a chronic course

Acute course of disease
<ul style="list-style-type: none"> <li>● Pulmonary infection (bacterial, <i>Pneumocystis jiroveci</i> pneumonia, aspergillus and mycoplasma pneumonia)</li> <li>● Pulmonary oedema</li> <li>● Pulmonary haemorrhage</li> <li>● Adult (acute) respiratory distress syndrome [ARDS]</li> <li>● Acute interstitial pneumonia [AIP]</li> <li>● Eosinophilic pneumonia (acute)</li> <li>● Radiation pneumonitis (acute)</li> </ul>
Subacute/chronic course of disease
<ul style="list-style-type: none"> <li>● Organising pneumonia</li> <li>● Bronchioloalveolar carcinoma</li> <li>● Lymphoma</li> <li>● Eosinophilic pneumonia (chronic)</li> <li>● Vasculitis (Churg-Strauss syndrome)</li> <li>● Lipoid pneumonia</li> <li>● Usual interstitial pneumonia [UIP]: idiopathic pulmonary fibrosis [IPF] and disease associated UIP</li> <li>● Nonspecific interstitial pneumonia [NSIP]</li> <li>● Hypersensitivity pneumonitis</li> <li>● Sarcoidosis</li> <li>● Lymphocytic interstitial pneumonia [LIP] (Sjögren syndrome, AIDS)</li> </ul>



- Consolidation is defined as an increase in lung density with obscuration of the underlying vessels and airway walls; an air bronchogram may be present
- Replacement of the alveolar air by fluid, cells, tissue or some other substances is the most frequent cause of consolidation. However, some diseases can produce very extensive confluent interstitial abnormalities and present as areas of lung consolidation on CT
- Both acute and subacute or chronic lung diseases can be responsible for the appearance of lung consolidation
- Airspace nodules and focal areas of ground-glass opacity are often seen in association with lung consolidation

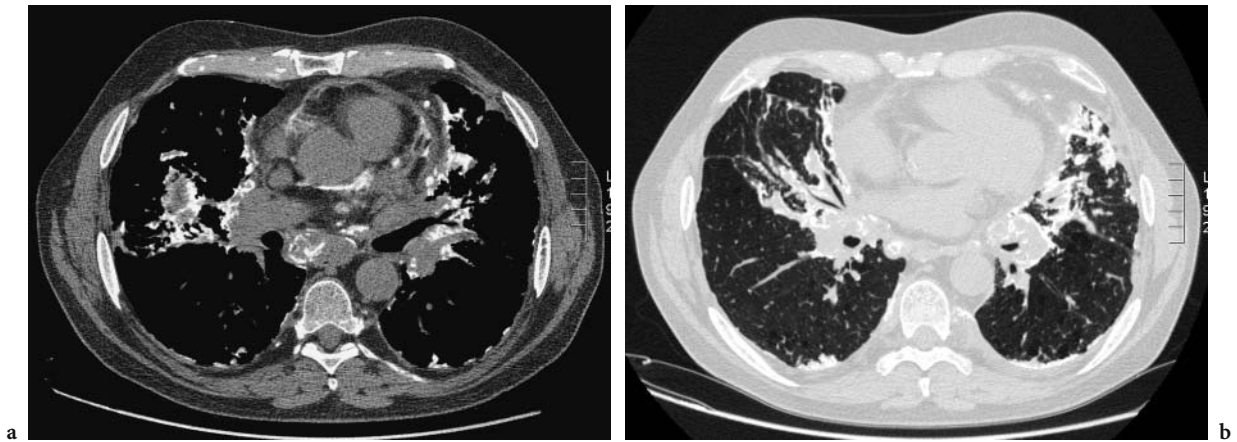
### 4.2.3

#### Increased Lung Attenuation Greater than Soft Tissue Density

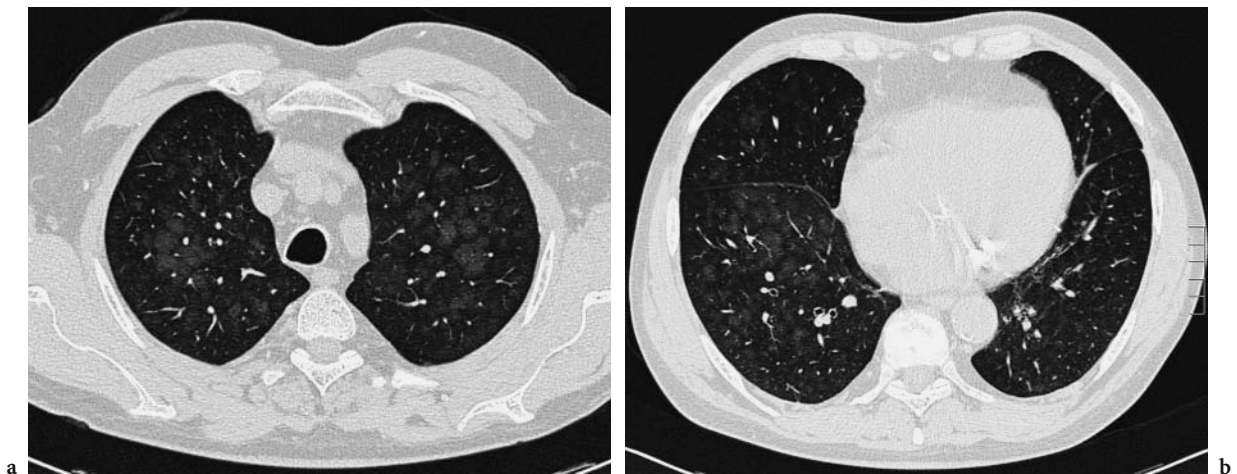
The most frequent cause of increased attenuation greater than soft tissue is multifocal lung calcification. These multifocal lung calcifications are seen in granulomatous diseases such as tuberculosis, silicosis, sarcoidosis and amyloidosis and are often associated with the presence of lung nodules (GRAHAM et al. 1992; IM et al. 1993; REMY-JARDIN et al. 1990a, 1990b) (Fig. 4.18).

A more diffuse increase in lung density greater than soft tissue can be seen in metastatic calcification (Figs. 4.19 and 4.20), alveolar microlithiasis, disseminated pulmonary ossification and as a re-





**Fig. 4.18a,b.** Pulmonary amyloidosis with large calcium-containing masses in both lungs. Note also the subpleural nodular deposits, some of which are partially or completely calcified



**Fig. 4.19a,b.** Metastatic calcification presenting as dense centrilobular ground-glass opacities in a patient with chronic renal failure and secondary hyperparathyroidism



**Fig. 4.20.** Metastatic calcification in consolidated lung in a patient with chronic renal failure and secondary hyperparathyroidism



sult of amiodarone lung toxicity (CLUZEL et al. 1991; JOHKOH et al. 1993; KUHLMAN et al. 1990).

In metastatic calcification, there is a deposition of calcium typically within the parenchymal and peribronchovascular interstitium. It can be seen in patients with hypercalcaemia due to an abnormal calcium and phosphate metabolism and is most common in patients with chronic renal failure and secondary hyperparathyroidism (HARTMAN et al. 1994; JOHKOH et al. 1993; KUHLMAN et al. 1989). These calcium deposits can be focal, centrilobular and diffuse (Fig. 4.19). On CT, they can present as areas of ground-glass opacity with calcification that may be inconspicuous or very dense or present as patchy areas of consolidation, again with calcification sometimes inconspicuous but sometimes with a very high density (HARTMAN et al. 1994; JOHKOH et al. 1993). In particular, consolidated lung parenchyma appears abnormally dense (Fig. 4.20).

Alveolar microlithiasis is characterised by the presence of widespread intra-alveolar calcifications and CT findings correspond closely to these pathologic findings. Calcified consolidations can be seen together with centrilobular nodular opacities, and sometimes linear opacities are present because of a preponderance of deposits at the periphery of the lobules and acini (CLUZEL et al. 1991; HELBICH et al. 1997; KORN et al. 1992). Disseminated ossification is a rare condition in which very small deposits of mature bone form within the lung parenchyma and can be associated with chronic heart disease (mitral stenosis), idiopathic pulmonary fibrosis (IPF) or asbestosis (GEVENOIS et al. 1994).

Finally, the drug amiodarone can accumulate in the lung and is in some patients responsible for a pulmonary toxic reaction with interstitial pneumonia and fibrosis. The consolidated lung parenchyma may appear abnormally dense. Usually the liver and spleen also appear abnormally dense because the drug also accumulates in these organs (KUHLMAN 1991; KUHLMAN et al. 1990; MARCHIORI et al. 2005).

### 4.3

#### Distribution Patterns and Diagnostic Algorithm

The study of the distribution of increased attenuation lung disease is predominantly a study of the regional distribution of this disease. However, the

relationship between the opacities and the secondary pulmonary lobule should be examined also. In particular, the centrilobular character of the disease can be helpful in the differential diagnosis. In addition, as indicated above, examining the acute, subacute or chronic character of the symptoms is important.

When one or more areas of increased lung attenuation are present, the reader should look for bronchiolar and vascular markings (Fig. 4.21). When these markings are preserved within the increased density areas, the differential diagnosis list of ground-glass opacity can be consulted (Table 4.1). When the vascular markings are obscured, the reader can refer to the differential diagnosis list of lung consolidation (Table 4.3). However, because of the high number of diseases that can be responsible for a simultaneous appearance of both types of increased opacity – which is also reflected in the great overlap between the two lists – often both lists need to be considered.

Depending on the presence of acute, subacute or chronic symptoms and the knowledge of whether the disease shows an acute, subacute or chronic course, the differential diagnosis can be refined (Tables 4.1 and 4.3).

If it is decided that the lung changes show the characteristics of ground-glass opacity, one should look for the presence of linear opacities projecting on this ground-glass opacity, i.e. one should look for the crazy-paving pattern (Table 4.2). In this pattern, diagnosis is also to some extent based on the presence of acute, subacute or chronic symptoms. However, both in the rather pure ground-glass opacity pattern and in the crazy-paving pattern, it is important to study the distribution of the lung opacities. Table 4.4 shows the diseases that have a predominant centrilobular and nodular, a subpleural, a patchy and a diffuse distribution pattern. Again there is substantial overlap in distribution, in part related to the aspecific character of causes of this pattern: both airspace filling processes and interstitial thickening processes can indeed cause ground-glass opacity. Given that the bronchioles enter the secondary pulmonary lobule at their centre, centrilobular ground-glass opacity is often the result of disease that shows a bronchial distribution in which the disease stimulus arrives at the centre of the lobule. Examples are early pulmonary infection, hypersensitivity pneumonitis and the small airway involvement of organising pneumonia (disease-associated and cryptogenic) (Fig. 4.22a). Since arterioles accompany

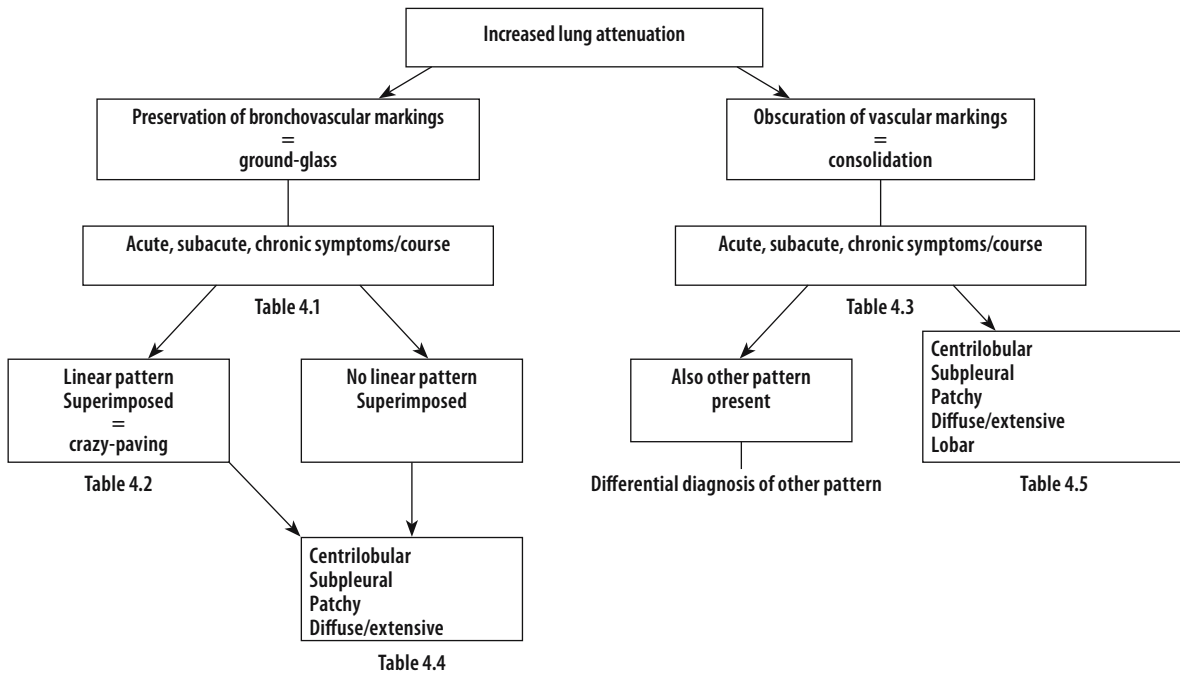


Fig. 4.21. Increased lung attenuation: diagnostic algorithm

the bronchioles and enter the lobules also at their centre, limited pulmonary haemorrhage, which may be caused by vasculitis, can also present as centrilobular (nodular) ground-glass opacity (Fig. 4.22b). Involvement of the centrilobular (peri)lymphatic interstitium such as in lymphangitic interstitial pneumonia (LIP) may also be responsible for the development of centrilobular ground-glass opacity. The centrilobular ground-glass opacities may, when disease progresses, result in a uniform involvement of the entire secondary pulmonary lobule and merging of pathology in the adjacent lobules may cause larger areas of ground-glass opacity. A subpleural distribution should suggest usual interstitial pneumonia and idiopathic pulmonary fibrosis, while a patchy distribution is usually related to chronic (interstitial) lung disease. Finally, extensive or diffuse involvement of the lung with ground-glass opacity usually suggests severe disease.

When the lung changes show the characteristics of lung consolidation, one should first look for other patterns (Fig. 4.21). If another pattern (especially the nodular pattern) is present, diagnosis should be based on this pattern because consolidation probably represents confluence. If lung consolidation is the dominant pattern, diagnosis can again be refined by

studying the patient's symptoms and the course of the disease (Table 4.3) and by looking at the distribution pattern (Table 4.5). Centrilobular (nodular) consolidation often corresponds with airspace filling resulting from disease that shows an airway distribution (Fig. 4.22a). Bronchopneumonia, organising pneumonia, bronchioloalveolar carcinoma and eosinophilic pneumonia may show this appearance. In addition, pulmonary haemorrhage (Fig. 4.22b) and LIP can cause centrilobular (nodular) consolidation. These centrilobular nodular consolidations may, when disease progresses, result in a uniform involvement of the entire secondary pulmonary lobule, and pathology merging in the adjacent lobules may cause larger areas of consolidation (MURATA et al. 1989). Subpleural consolidations suggest eosinophilic pneumonia and organising pneumonia, whereas a patchy distribution often corresponds with chronic disease. A lobar consolidation may be seen in (lobar) pneumonia, bronchioloalveolar carcinoma, organising pneumonia and lymphoma. As in ground-glass opacity, diffuse involvement usually corresponds with severe disease.

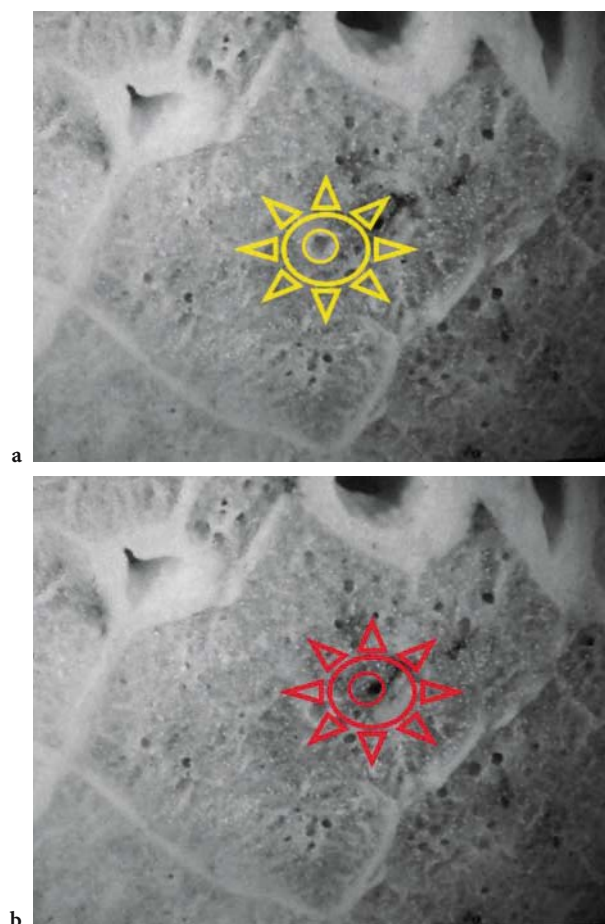
Finally, the study of the regional distribution of disease can be helpful in the differential diagnosis (Table 4.6).

Table 4.4. Distribution pattern of ground-glass opacity

Centrilobular nodular (ill-defined soft tissue nodules)
<ul style="list-style-type: none"> <li>● Hypersensitivity pneumonitis</li> <li>● Organising pneumonia</li> <li>● Pulmonary infection (viral, bacterial, fungus)</li> <li>● Pulmonary oedema</li> <li>● Pulmonary haemorrhage</li> <li>● Vasculitis</li> <li>● Metastatic calcification</li> <li>● Lymphocytic interstitial pneumonia [LIP] (Sjögren syndrome, AIDS)</li> </ul>
Subpleural
<ul style="list-style-type: none"> <li>● Usual interstitial pneumonia [UIP]: idiopathic pulmonary fibrosis [IPF] and disease associated UIP</li> <li>● Eosinophilic pneumonia</li> <li>● Organising pneumonia</li> <li>● Asbestosis</li> </ul>
Patchy
<ul style="list-style-type: none"> <li>● Nonspecific interstitial pneumonia [NSIP]</li> <li>● Desquamative interstitial pneumonia [DIP]</li> <li>● Hypersensitivity pneumonitis</li> <li>● Alveolar proteinosis</li> <li>● Pulmonary haemorrhage</li> <li>● Vasculitis</li> <li>● Sarcoidosis</li> </ul>
Diffuse/extensive
<ul style="list-style-type: none"> <li>● Hypersensitivity pneumonitis</li> <li>● Smoking-related interstitial lung disease (Respiratory bronchiolitis - interstitial lung disease [RB-ILD], desquamative interstitial pneumonia [DIP])</li> <li>● Nonspecific interstitial pneumonia [NSIP]</li> <li>● Pulmonary infection (viral, bacterial, fungus)</li> <li>● Pulmonary oedema</li> <li>● Pulmonary haemorrhage</li> <li>● Adult (acute) respiratory distress syndrome [ARDS]</li> <li>● Acute interstitial pneumonia [AIP]</li> <li>● Alveolar proteinosis</li> </ul>

Table 4.5. Distribution pattern of lung consolidation

Centrilobular nodular (ill* or sharply** defined soft tissue nodules)
<ul style="list-style-type: none"> <li>● Hypersensitivity pneumonitis*</li> <li>● Organising pneumonia**</li> <li>● Bronchioloalveolar carcinoma**</li> <li>● Aspiration*</li> <li>● Pulmonary infection* (bacterial, tuberculosis, aspergillosis)</li> <li>● Pulmonary oedema*</li> <li>● Pulmonary haemorrhage*</li> <li>● Vasculitis*</li> <li>● Lymphocytic interstitial pneumonia [LIP]* (Sjögren syndrome, AIDS)</li> </ul>
Subpleural
<ul style="list-style-type: none"> <li>● Eosinophilic pneumonia (chronic)</li> <li>● Organising pneumonia</li> <li>● Usual interstitial pneumonia [UIP]: idiopathic pulmonary fibrosis [IPF] and disease associated UIP</li> </ul>
Patchy
<ul style="list-style-type: none"> <li>● Nonspecific interstitial pneumonia [NSIP]</li> <li>● Desquamative interstitial pneumonia [DIP]</li> <li>● Hypersensitivity pneumonitis</li> <li>● Pulmonary haemorrhage</li> <li>● Vasculitis</li> <li>● Sarcoidosis</li> </ul>
Diffuse/extensive
<ul style="list-style-type: none"> <li>● Hypersensitivity pneumonitis</li> <li>● Nonspecific interstitial pneumonia [NSIP]</li> <li>● Pulmonary infection (bacterial)</li> <li>● Pulmonary oedema</li> <li>● Pulmonary haemorrhage</li> <li>● Adult (acute) respiratory distress syndrome [ARDS]</li> <li>● Acute interstitial pneumonia [AIP]</li> <li>● Alveolar proteinosis</li> </ul>
Lobar
<ul style="list-style-type: none"> <li>● Pulmonary infection (lobar pneumonia)</li> <li>● Bronchioloalveolar carcinoma</li> <li>● Organising pneumonia</li> <li>● Lymphoma</li> </ul>



**Fig. 4.22a,b.** Centrilobular ground-glass opacity and consolidation is predominantly the result of airway/airspace filling, which can result from airway, or vascular distribution of disease

**Table 4.6.** Regional distribution of increased attenuation lung diseases

Upper lung versus Lower lung versus Diffuse
<ul style="list-style-type: none"> <li>● <b>Upper:</b> sarcoidosis, tuberculosis, chronic eosinophilic pneumonia</li> <li>● <b>Lower:</b> oedema, usual interstitial pneumonia [UIP] (idiopathic pulmonary fibrosis and disease associated UIP), asbestosis, non-specific interstitial pneumonia [NSIP], desquamative interstitial pneumonia [DIP], lipoid pneumonia, cryptogenic organising pneumonia, alveolar pulmonary haemorrhage</li> <li>● <b>Diffuse:</b> hypersensitivity pneumonitis, diffuse pneumonia, lymphangitic spread of tumor, sarcoidosis</li> </ul>
Central lung versus Peripheral lung
<ul style="list-style-type: none"> <li>● <b>Central:</b> sarcoidosis, lymphangitic spread of tumor, alveolar proteinosis</li> <li>● <b>Peripheral:</b> usual interstitial pneumonia [UIP] (idiopathic pulmonary fibrosis and disease associated UIP), asbestosis, nonspecific interstitial pneumonia [NSIP], chronic eosinophilic pneumonia, cryptogenic organising pneumonia, acute interstitial acute interstitial pneumonia [AIP], desquamative interstitial pneumonia [DIP], hypersensitivity pneumonitis, septic emboli, pulmonary embolism</li> </ul>
Posterior versus Anterior lung
<ul style="list-style-type: none"> <li>● <b>Posterior:</b> pulmonary oedema, adult respiratory distress syndrome [ARDS] usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis and disease associated UIP), asbestosis, non-specific interstitial pneumonia [NSIP], sarcoidosis, hypersensitivity pneumonitis, lipoid pneumonia</li> </ul>
Can be unilateral or asymmetric
<ul style="list-style-type: none"> <li>● Pneumonia, lymphangitic spread of tumour, sarcoidosis</li> </ul>

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# Decreased Lung Attenuation

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## 5.1

### Introduction

The decreased lung attenuation pattern develops when the density of the lung parenchyma decreases. As mentioned in Chapter 2, the normal lung density on CT is slightly higher than air and is determined by the balance between air in the airspaces and in the small airways, on one hand, and the soft tissue structures that have a higher density than air but that are as such not individually visible on the other hand. These soft tissue structures include the (interstitial) lung tissues, the wall of the small airways and blood vessels and the blood in these vessels. A decrease in lung attenuation can be observed when this balance is disturbed by either an abnormal increase in the amount of air, an abnormal decrease in the intravascular blood volume with, as a result, a smaller calibre of the small vessels, and in case of loss of (interstitial) lung tissue. Each of these phenomena may result in a different decreased lung attenuation pattern (Fig. 5.1).

A decrease in blood flow to an area of the lung causes a reduction in the amount of blood in the small vessels in that area, resulting in a reduction of the size of these vessels. This hypoperfusion can be responsible for a decrease in X-ray attenuation and hence creates an area of decreased lung attenuation.

A relative increase in the amount of air in the airspaces will also decrease lung opacity. Such an increase in the amount of air is seen when air trapping occurs. Air trapping is defined as a retention of excess gas (air) in all or part of the lung, especially during expiration, either as a result of complete or partial airway obstruction or as a result of local abnormalities in pulmonary compliance (AUSTIN et al. 1996).

Lung attenuation may also decrease when lung tissue is destroyed and when loss of lung tissue occurs. The relationship between tissue and air is then disturbed again and air becomes the dominant component, although a concomitant increase in lung tissue or blood flow could normalise the overall lung density. The areas of decreased lung attenuation caused by lung destruction and tissue loss can look like cysts. Real cysts are thin-walled areas of low density that are well defined and circumscribed and that have a cellular wall. Cyst-like areas of decreased lung attenuation may develop because necrosis occurs in pre-existing nodules or nodular opacities (cavitary nodules). Also pneumatoceles and cystic bronchiectasis may present as cystic lung disease. However, lung destruction and loss of lung tissue is most frequently the result of pulmonary emphysema.

### Decreased lung attenuation

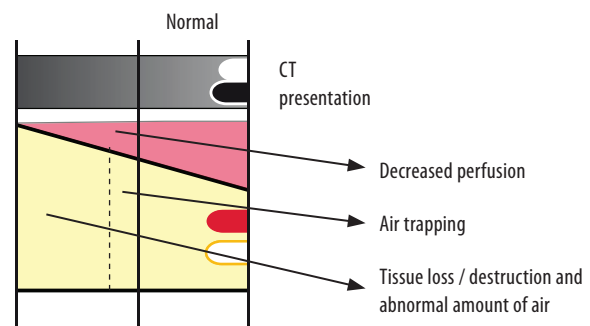


Fig. 5.1. A decrease in CT lung attenuation can be the result of decreased perfusion, air trapping, tissue loss/destruction and the presence of an abnormal amount of air

## 5.2

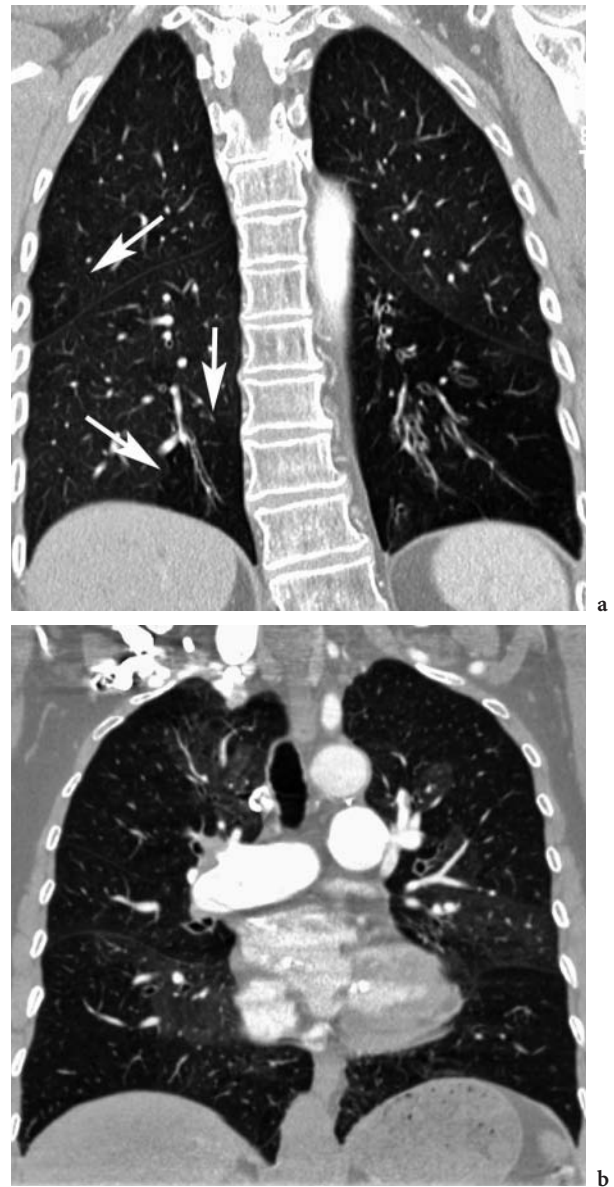
### Types of Low-Attenuation Patterns

#### 5.2.1

#### Hypoperfusion and Mosaic Perfusion

A decrease in perfusion or hypoperfusion of a part of the lung may be due to 1) narrowing or obliteration of the airway(s) that ventilate(s) that lung area or 2) narrowing or obliteration of the blood vessel(s) that perfuse(s) that lung area. In case of airway narrowing, hypoperfusion occurs because air trapping and hypoventilation distal to this narrowed airway cause reflex vasoconstriction (LYNCH et al. 1990; MARTI-BONMATI et al. 1989; WEBB 1994). These areas of relatively decreased lung density can be small or large and often appear to correspond to lobules, segments, lobes (Fig. 5.2a) or even an entire lung. This geographical distribution is not surprising and corresponds with well-delineated lung areas distal to the airway or vessel that is obstructed (Table 5.1). If normal lung tissue surrounds these areas of decreased perfusion, this normal lung tissue often has a higher than normal density (ground-glass density) resulting from compensatory increased perfusion.

When the distribution of these areas of decreased attenuation is patchy, which is often the case in airway disease, and when the surrounding normal lung areas show increased lung density resulting from compensatory hyperperfusion, a typical pattern called the “mosaic pattern” occurs (LYNCH et al. 1990; MARTI-BONMATI 1989; MURATA et al. 1996; WEBB 1994; WEBB et al. 1993a). This pattern, in which areas of decreased attenuation are adjacent to areas with increased attenuation, has also been called “mosaic perfusion” and “mosaic oligoemia” referring to the perfusion changes that are responsible for this phenomenon (WEBB et al. 1993a) (Fig. 5.3). These perfusion changes also are very often directly visible because the larger blood vessels that can be identified individually are usually smaller in size in the hypoattenuation parts and larger in calibre in the hyperattenuation parts of the mosaic pattern. This observation is very important because it can be used to differentiate the mosaic pattern caused by mosaic perfusion from the mosaic pattern caused by patchy distributed ground-glass opacities surrounded by normal lung tissue (Fig. 5.4). In this latter condition, blood vessels usually appear equal in size throughout the lung (IM et al. 1996). In addition, in our experience, the ground-glass opacities are often ill defined,

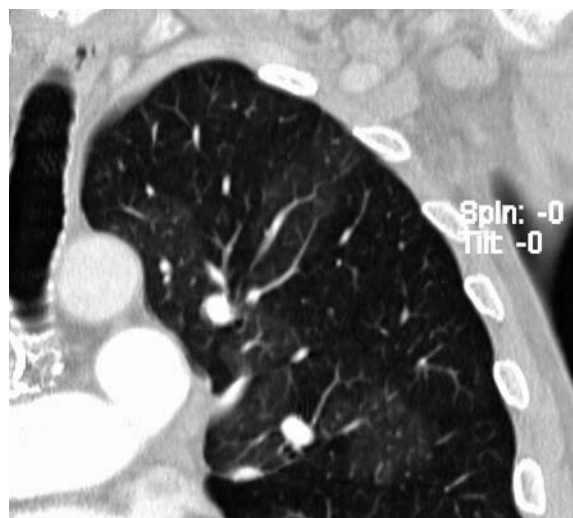


**Fig. 5.2a,b.** Widespread hypoperfusion caused by airway obstruction as a result of small airway disease (a) and by direct vascular obstruction as a result of recurrent pulmonary embolism (b). In (a), a large area of decreased perfusion is seen in the left lower lobe, while smaller areas are seen in the right lung (arrows). Note the decreased lung density and the reduction in size and number of the vessels without obvious lung destruction. The presence of bronchial wall thickening suggests airway disease and the areas of reduced lung perfusion probably result from narrowing of the small airways that ventilate these lung regions. In (b), multiple large areas of decreased perfusion are seen in the periphery of both lungs. Redistribution of the blood to the normal lung areas causes increased perfusion and increased density in these areas. The dilatation of the central pulmonary arteries suggests pulmonary arterial hypertension and a vascular cause of the abnormal perfusion

**Table 5.1.** Diseases associated with areas of low attenuation and mosaic perfusion.

Airway disease
<ul style="list-style-type: none"> <li>● Bronchiolitis obliterans (constrictive bronchiolitis)               <ul style="list-style-type: none"> <li>● Idiopathic (rare) (W)</li> <li>● Healed infections (especially viral and mycoplasma) (P)</li> <li>● Component of chronic bronchitis, cystic fibrosis, bronchiectasis (P)</li> <li>● Inhalation of toxin or fume (including cigarette smoke) (P)</li> <li>● Connective tissue diseases (rheumatoid arthritis, Sjögren syndrome) (W)</li> <li>● Transplantation-associated airway injury (bone marrow, heart-lung, lung) (W)</li> <li>● Drug reaction (penicillamine)</li> </ul> </li> <li>● Hypersensitivity pneumonitis (granulomatous inflammation of the bronchiolar wall)</li> <li>● Sarcoidosis (granulomatous inflammation of the bronchiolar wall)</li> <li>● Airway disease related to Langerhans cell histiocytosis and lymphangioleiomyomatosis</li> <li>● Airway disease related to AIDS</li> <li>● Bronchiectasis</li> <li>● Asthma (bronchiolar spasm)</li> <li>● Acute pulmonary embolism (bronchiolar spasm)</li> <li>● Vasculitis (bronchiolar spasm)</li> <li>● Scarring</li> </ul>
Vascular disease
<ul style="list-style-type: none"> <li>● Chronic pulmonary embolism and related pulmonary arterial hypertension (P)</li> <li>● Idiopathic pulmonary arterial hypertension (less frequent) (W)</li> <li>● Pulmonary arterial hypertension caused by cardiac and pulmonary disease (less frequent)</li> </ul>

The diseases listed under airway disease can also cause air trapping. P, patchy; W widespread



**Fig. 5.3.** Mosaic perfusion in a patient with chronic pulmonary embolism and pulmonary hypertension. Areas of decreased attenuation are adjacent to areas with increased attenuation. Note that the blood vessels are smaller in size in the hypoattenuation parts and larger in the hyperattenuation parts of the mosaic perfusion



a



b

**Fig. 5.4a,b.** Mosaic pattern as a result of a patchy distribution of ground-glass opacity mimicking mosaic perfusion: inspiratory (a) and expiratory (b) scan. Differential diagnosis is predominantly based on normal vessel size in the high- and low-density areas, on the fact that the areas of increased density are ill-defined and poorly margined and that the high density areas become very dense on expiratory CT (b)



an observation that can be important in the differential diagnosis since the difference in vessel calibre is not always present (ARAKAWA et al. 1998) (Table 5.2).

Hypoperfusion and mosaic perfusion can be attributable to airway disease and to vascular disease. Airway disease is the most frequent cause and the findings are most common in patients with bronchiolitis obliterans (constrictive bronchiolitis) and diseases associated with small airway obstruction, but can also be seen as a result of large bronchial obstruction (ARAKAWA and WEBB 1998b; WEBB 1997; WORTHY et al. 1997b) (Table 5.1). When hypoperfusion and mosaic perfusion stem from airway disease, they are indirect indicators that the small airways are involved. Usually there are also direct signs of (larger) airway involvement, i.e. abnormal dilated or thick-walled airways are visible in the relatively lucent lung regions (ARAKAWA et al. 1998; WEBB 1994, 1997; WORTHY et al. 1997a) (Fig. 5.2a). Air trapping on expiratory scans, described in the next section, is often helpful to confirm the diagnosis.

The most frequent cause of areas of hypoperfusion and mosaic perfusion resulting from vascular obstruction is chronic pulmonary embolism (CPE) (BERGIN et al. 1996; SCHWICKERT et al. 1994). The combination of these findings with enlargement of the main pulmonary arteries is very suggestive for

the diagnosis of pulmonary arterial hypertension (PAH) caused by CPE (Fig. 5.2b). Hypoperfusion and mosaic perfusion is seen significantly less often in patients with idiopathic pulmonary arterial hypertension (PAH) and PAH caused by cardiac or pulmonary disease (SCHERRICK et al. 1997).

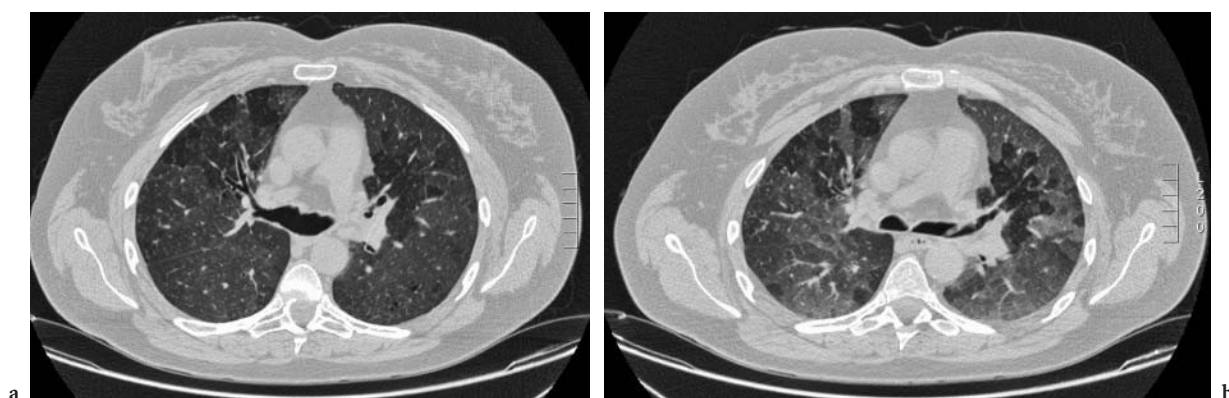
It should be emphasised again that often in healthy individuals, one or more areas of local hypoperfusion can be seen. They are limited in size to one or two adjacent secondary pulmonary lobules and are most typically seen in the superior segments of the lower lobes, posterior to the major fissures and in the anterior part of the middle lobe and lingula, especially in older patients and in smokers or ex-smokers (CHEN et al. 1998; LEE et al. 2000; VERSCHAKELLEN et al. 1998; WEBB et al. 1993b). They are sometimes only seen on expiratory scans, and when already visible on inspiratory scans, expiration makes them more clearly visible because of air trapping (Fig. 2.11).

A special pattern of densities may occur when a mosaic perfusion is combined with ground-glass opacity or consolidation. This combination of mixed densities has been termed the head-cheese sign and is most frequently seen in hypersensitivity pneumonitis, sarcoidosis and atypical infections with associated bronchiolitis (CHUNG et al. 2001) (Fig. 5.5).

**Table 5.2.** Mosaic pattern: signs that can be helpful to differentiate between mosaic perfusion and patchy ground-glass opacities

Mosaic perfusion		Patchy ground-glass
Airway disease	Vascular disease	
Both low- and high-density areas are abnormal		High-density areas are abnormal. Lower-density areas reflect normal lung attenuation
Reduced vessel size in low-density areas		Normal vessel size in low-density areas
Vessel size in high-density areas may be increased		Normal vessel size in high-density areas
Thick-walled and dilated airways may be visible	Dilatation of central pulmonary arteries	
Low-density areas are often (multi)lobular	Low-density areas are large and often not lobular	
Border between high- and low-density areas is often sharp		Areas of increased density are often ill defined and poorly margined
High-density areas are almost never centrilobular		High-density areas can be centrilobular
Pattern accentuated on expiratory CT because of air trapping in the low-density areas	No pattern accentuation on expiratory CT	No pattern accentuation on expiratory CT. High-density areas become very dense





**Fig. 5.5a,b.** Patient with hypersensitivity pneumonitis combining diffuse ground-glass opacity with patchy areas of decreased lung density creating the head-cheese pattern: CT at suspended deep inspiration (a) and CT at suspended deep expiration (b). On expiratory CT (b), these areas of decreased lung attenuation are accentuated because of air trapping

Table 5.1 shows the most frequent causes of lung hypoperfusion and mosaic perfusion (ARAKAWA and WEBB 1998a,b; ARAKAWA et al. 2002; GARG et al. 1994; GELMAN et al. 1999; GLEESON et al. 1996; HANSELL et al. 1994, 1996, 1998; KITAHARA et al. 1989; KNUDSON et al. 1991; LUCIDARME et al. 1998; MARTI-BONMATI et al. 1989; NEWMAN et al. 1994; PARK et al. 1997; SMALL et al. 1996; STERN et al. 1992, 1994a; SWEATMAN et al. 1990; WEBB 1997; YANG et al. 1997).

## 5.2.2

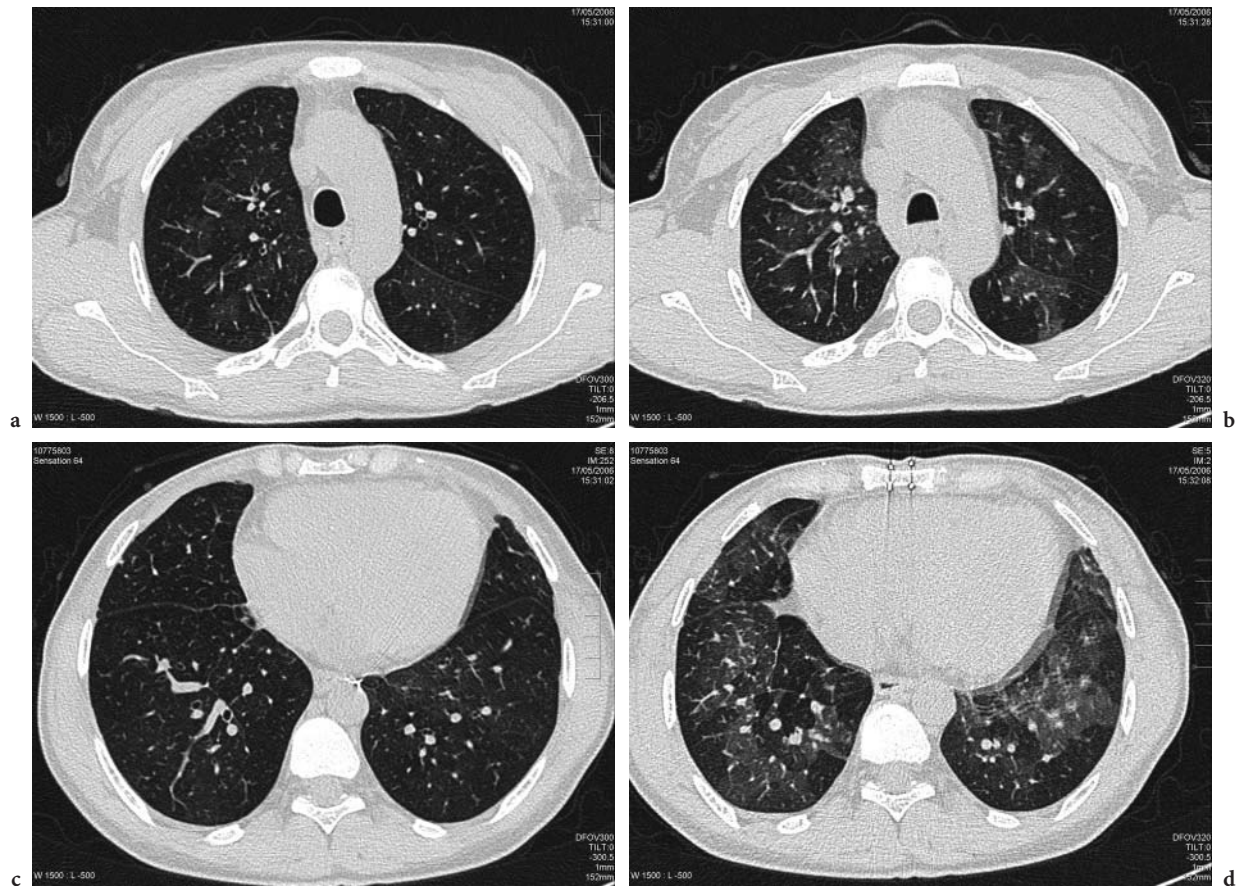
### Air Trapping

Air trapping is defined as a retention of excess gas (air) in all or part of the lung, especially during expiration, either as a result of complete or partial airway obstruction or as a result of local abnormalities in pulmonary compliance (AUSTIN et al. 1996). The diagnosis of air trapping should be made on expiratory scans and is usually clear when the abnormality is patchy in distribution because abnormal lucent areas are then contrasted with normal surrounding lung regions (Fig. 5.6). Air trapping can be nonanatomic but most often corresponds with an individual secondary pulmonary lobule with several adjacent lobules or with a lung segment. It may, however, involve an entire lobe or even an entire lung (RINGERTZ et al. 1989; STERN and WEBB 1993). Lobular or segmental air trapping is associated with diseases that produce small airway abnormalities, whereas air trapping in a lobe or lung usually indicates large airway disease or generalised small airway abnormalities (RINGERTZ et al. 1989; STERN and WEBB 1993).

In some patients, one or more areas of air trapping are seen on the expiratory scans, while the inspiratory scans show no hypoperfusion or hypopatternation areas. When limited to one or a few pulmonary secondary lobules, this may not have an influence on the pulmonary function, but when extensive this indicates the presence of obstructive lung disease. Air trapping zones on expiratory scans with normal inspiratory scans or with abnormal inspiratory scans, although without any perfusion abnormalities, have been described in patients with



- The presence of areas of hypoperfusion and of mosaic perfusion may be due to airway disease and vascular disease
- Mosaic perfusion can often be differentiated from the mosaic pattern resulting from patchy distributed ground-glass opacities on the basis of calibre differences of the blood vessels
- When dilated and thick-walled airways can be recognised in the lucent lung regions, airway disease is suggested as the cause of hypoperfusion and mosaic perfusion
- A combination of areas of hypoperfusion and mosaic perfusion, with enlargement of the central pulmonary arteries, suggests a vascular cause, i.e. chronic pulmonary embolism with pulmonary arterial hypertension
- The combination of areas of mosaic perfusion and ground-glass opacity creates a pattern termed the head-cheese pattern



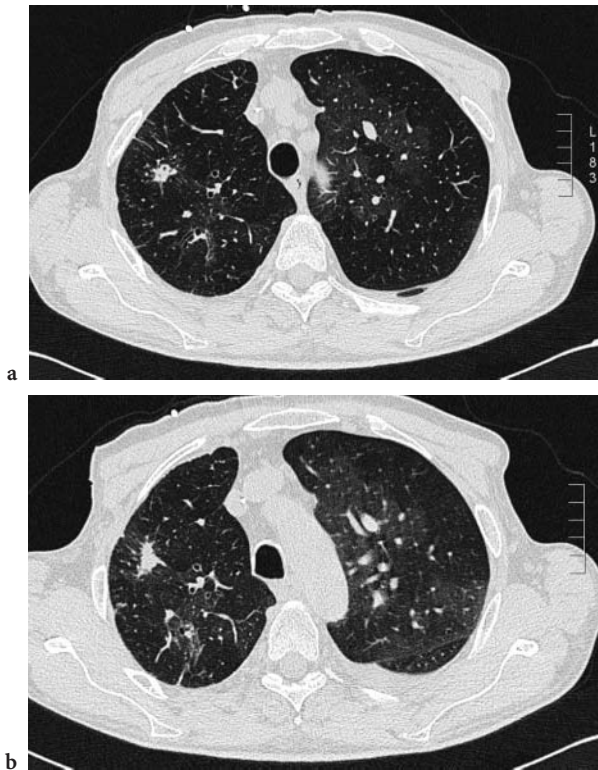
**Fig. 5.6a–d.** Multiple areas of air trapping in a patient with graft versus host disease. Note that the low-density areas are hardly visible as mosaic perfusion on the scans at suspended deep inspiration (a) and (c); (b) and (d) are scans at suspended deep expiration

bronchiectasis, bronchiolitis obliterans, asthma, chronic bronchitis, cystic fibrosis, hypersensitivity pneumonitis and sarcoidosis (ARAKAWA and WEBB 1998a). Results of pulmonary function tests in these patients were intermediate between patients with normal inspiratory and expiratory scans and those with air trapping and abnormal inspiratory scans.

When the areas of air trapping on the expiratory scans correspond with the areas of hypoperfusion on the inspiratory scans, a strong suspicion that the hypoperfusion is secondary to airway narrowing and not to primary vascular obstruction arises. Indeed in the case of vascular obstruction, air trapping is not expected to occur on the expiratory scans because the airways are not involved, and lung density should increase in both the high and the low lung density areas (Fig. 5.7). In the same way, mosaic perfusion, seen on inspiratory scans, can be attributed to small airway disease when this mosaic perfusion is accentuated on the expiratory scans: high-attenuation parts increase in density and reduce in size be-

cause of an expiratory decrease in air, whereas the low-attenuation parts remain unchanged in density and size because of air trapping (ARAKAWA et al. 1998; ARAKAWA and WEBB 1998a; CHEN et al. 1998; LUCIDARME et al. 1998; STERN et al. 1992; WEBB et al. 1993b) (Fig. 5.6). The differential diagnosis between inhomogeneous ground-glass opacity and mosaic perfusion caused by vascular disease on an expiratory scan can be difficult because in both circumstances high- and low-density areas will increase in density during expiration. As mentioned earlier, the presence or absence of calibre differences of the vessels and the sharp vs the blurred delineation of the ground-glass areas should be helpful to differentiate between mosaic perfusion and patchy ground-glass opacity, respectively (ARAKAWA et al. 1998; WORTHY et al. 1997a) (Fig. 5.4) (Table 5.2).

Large areas of decreased lung perfusion can mimic severe confluent centrilobular emphysema and panlobular emphysema. Signs that are helpful in the differential diagnosis are listed in Table 5.3



**Fig. 5.7a,b.** Inspiratory (a) and expiratory (b) CT in a patient with mosaic perfusion caused by chronic pulmonary embolism. Mosaic perfusion is not accentuated on the expiratory scan, i.e. no air trapping is present. The opacity in the right lung is caused by an aspergillus infection

and will be discussed in Sect. 5.2.4 on pulmonary emphysema.

The head-cheese pattern described in the previous section, which combines ground-glass opacities, and mosaic perfusion as an expression of a mixed infiltrative and obstructive disease, may be accentuated on the expiratory scans because the hypoattenuation areas show air trapping (Fig. 5.5). It may also be possible that this head-cheese pattern is only appreciated on the expiratory scans because the hypoventilated areas only then become apparent.

- Air trapping is a sign of airway narrowing
- Air trapping may be seen on expiratory scans in patients with normal inspiratory scans
- When air trapping on the expiratory CT scan accentuates the area of hypoperfusion seen on an inspiratory CT scan, this hypoperfusion is very likely the result of airway narrowing. If this area of hypoperfusion increases in density on the expiratory scans, the cause is probably a vascular disease

The diseases that can cause air trapping can also be found in Table 5.1 under the heading “Airway Disease”.

**Table 5.3.** CT features that help to differentiate between decreased lung perfusion, severe confluent centrilobular emphysema and panlobular emphysema as causes of decreased lung density

Decreased lung perfusion	Severe or confluent centrilobular emphysema	Panlobular emphysema
Patchy (mosaic perfusion) lobular, segmental, lobar, lung, periphery	Diffuse, lobar, bilateral, upper lung	Diffuse, lobar, bilateral, basal lung
Decrease in size and number of vessels without obvious signs of lung destruction	Obvious signs of lung destruction	Extreme paucity of vessels without (early disease) or with (advanced disease) signs of lung destruction
In case of bronchiolar cause, abnormal thick-walled and sometimes dilated airways	Abnormal thick-walled and sometimes dilated airways present when smoking history	Usually no airway wall thickening or dilatation except when smoker
In case of vascular cause, enlargement of main pulmonary arteries because of pulmonary hypertension	Enlargement of main pulmonary arteries because of pulmonary hypertension	Enlargement of main pulmonary arteries because of pulmonary hypertension
	Mild centrilobular emphysema, paraseptal emphysema and bullae are often present	Panlobular emphysema is usually the only type of emphysema present



### 5.2.3 Cystic Lung Disease

**Table 5.4.** Differential diagnosis of cystic and cyst-like lung changes

Lung cysts
<ul style="list-style-type: none"> <li>● End-stage pulmonary fibrosis: honeycombing or honeycomb cysts</li> <li>● Lymphangiomyomatosis (LAM): cysts are round and uniform in size</li> <li>● Langerhans histiocytosis: cysts can have bizarre shapes and different sizes</li> <li>● Lymphocytic interstitial pneumonia (LIP) (Sjögren syndrome, AIDS): cysts are thin-walled and may be multiple</li> <li>● Bronchogenic cyst</li> </ul>
Cavitary nodules (cyst-like lesions)
<ul style="list-style-type: none"> <li>● Langerhans histiocytosis</li> <li>● Metastatic tumour</li> <li>● Septic embolism</li> <li>● Wegener's granulomatosis</li> <li>● Tuberculosis</li> <li>● Pulmonary aspergillosis</li> <li>● Rheumatoid arthritis (necrobiotic nodule)</li> <li>● Sarcoidosis (less frequent)</li> </ul>
Other causes
<ul style="list-style-type: none"> <li>● Pneumatocoeles (in staphylococcal and Pneumocystis jiroveci pneumonia, post-traumatic)</li> <li>● Bronchiectasis</li> </ul>

Low attenuation lung changes can appear as lung cysts or cyst-like structures, two terms that usually are not used to describe lung changes in emphysema.

**Lung cyst** and **cystic airspace** are terms that refer to well-defined, circumscribed and often rounded lesions with a thin wall (usually less than 3 mm thick). This wall may be uniform or may be varied in thickness and is composed of one or a variety of cellular elements that are usually fibrous or epithelial in nature (NAIDICH 1991; TUDDENHAM 1984). Cysts usually contain air but may also contain liquid, solid or semisolid material (AUSTIN et al. 1996; NAIDICH 1991). The most frequent cause of cystic lung changes is advanced fibrosis giving rise to honeycombing



**Fig. 5.8.** Honeycombing is a frequent cause of cystic lung changes and is the result of advanced lung fibrosis. Patient with usual interstitial pneumonia (UIP) and peripheral subpleural honeycomb cysts

or honeycomb cysts (HOGG 1991; NISHIMURA et al. 1992) (Fig. 5.8). Honeycombing is characterised by the presence of air-filled cystic spaces that often predominate in a peripheral subpleural location. These cysts can have a diameter ranging from several millimetres to several centimetres and a wall thickness between 1 and 3 mm. This wall consists of fibrous tissue lined by bronchiolar epithelium, is usually clearly definable and is shared by adjacent cysts. The latter phenomenon is rather specific for honeycombing and not seen in cysts that are found in patients with lymphangiomyomatosis (LAM) (Fig. 5.9), Langerhans cell histiocytosis (Fig. 5.10) and lymphocytic interstitial pneumonia (LIP) (Fig. 5.11) (Table 5.5). Sometimes honeycombing is associated with the presence of large cysts with a diameter up to several centimetres. These large cysts are also predominantly subpleural in location and although usually seen in the upper lobes, they may occur at the lung bases as well (AQUINO et al. 1994; WORTHY et al. 1998). Honeycombing is discussed in detail in Sect. 7.2.6 in Chapter 7.

**Cavitary nodules** are cyst-like structures that are defined as areas of decreased lung attenuation that develop because necrosis occurs in pre-existing nodules (Fig. 5.12). Cavitary nodules may look very similar to real cysts but usually have thicker and irregular walls.

**Pneumatocoeles** are defined as thin-walled air-filled spaces within the lung (TUDDENHAM 1984). They usually occur in association with pulmonary

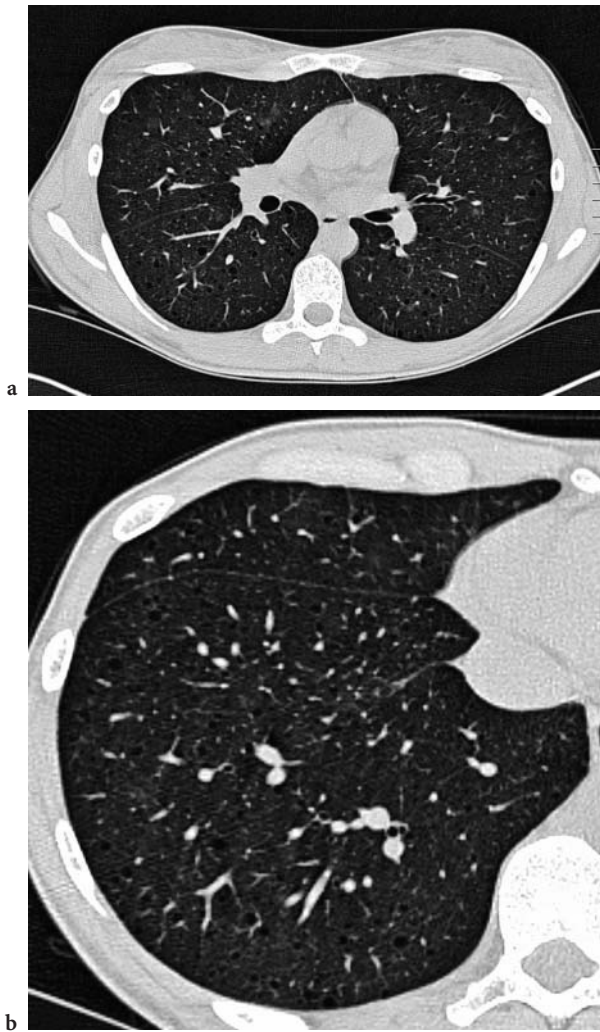


Fig. 5.9a,b. Lymphangiomatosis (mild disease). Diffuse thin-walled and round cysts in both lungs. Note that the costophrenic angles are also involved (b)

infection, notably staphylococcal and *Pneumocystis jiroveci* infections, and with post-traumatic pulmonary laceration (Fig. 5.13). They are usually transient but scarring may occur during healing. Pneumatoceles have an appearance that is similar to lung cysts or bullae on CT.

**Bronchiectasis** as such is not part of the cystic lung changes but needs to be discussed here because bronchiectasis can mimic cystic lung disease. Bronchiectasis is generally defined as localised, irreversible bronchial dilatation, very often with thickening of the bronchial wall (AUSTIN et al. 1996; GRENIER et al. 1993) (Fig. 5.14). Generally, bronchial dilatation is considered when the internal diameter of the bronchus is

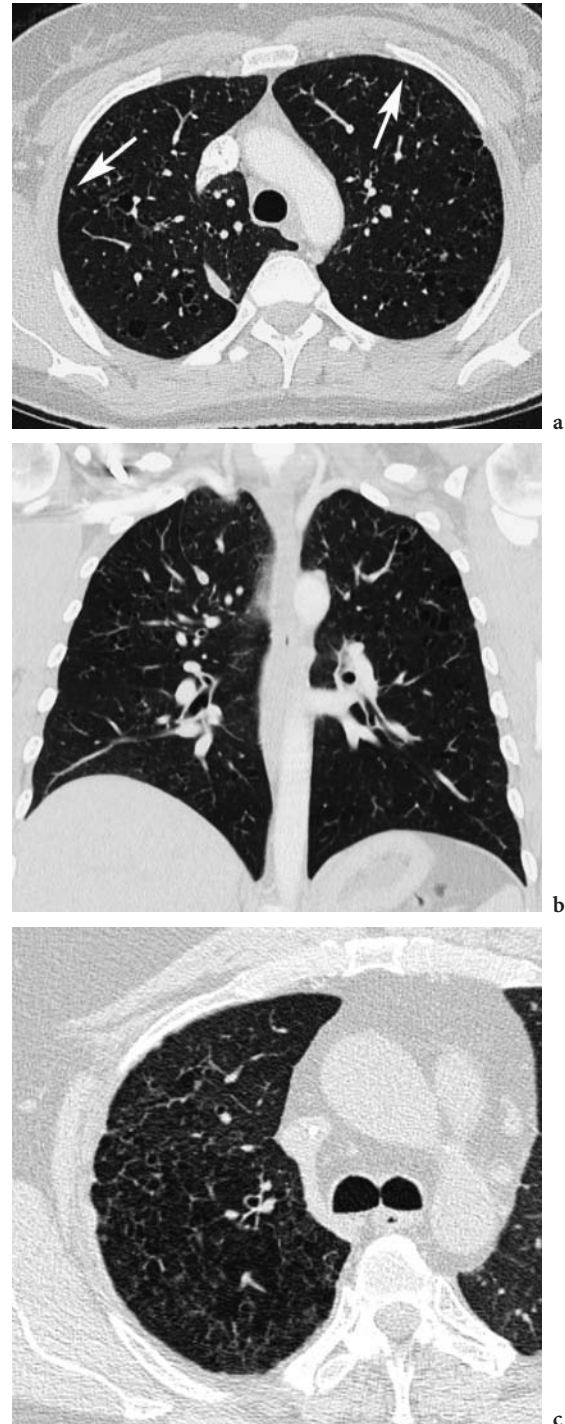


Fig. 5.10a–c. Cystic lung changes in a patient with Langerhans cell histiocytosis. Early disease (a) and (b): irregular shaped, thin- and thick-walled cysts, sometimes confluent, are seen in the upper lobes of both lungs. Note also the presence of a few centrilobular nodules (arrows). Advanced disease (c) in a patient who underwent a left-sided lung transplantation: multiple confluent thick-walled cysts are seen in the upper part of the lung



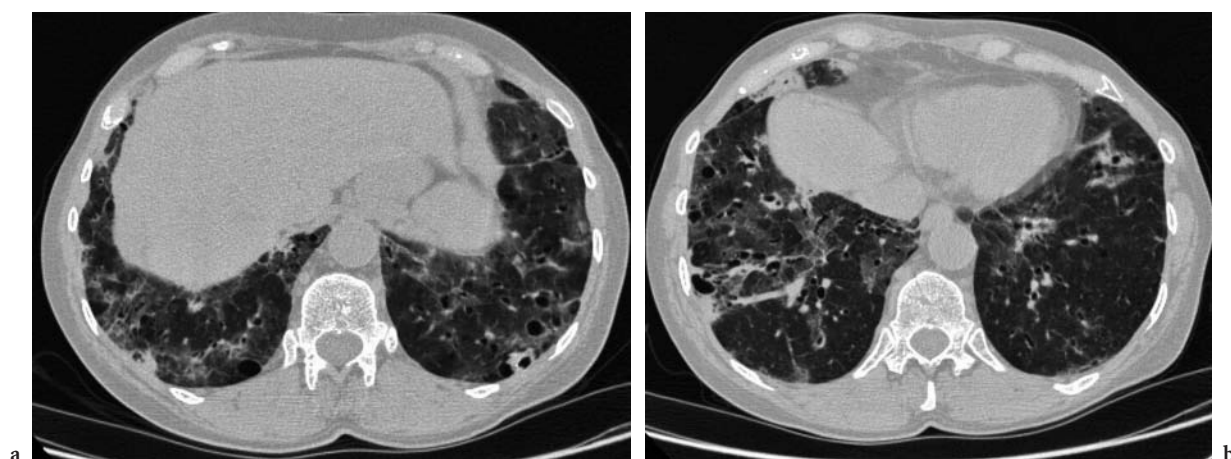


Fig. 5.11a,b. Lymphocytic interstitial pneumonia (LIP). A few thin-walled cystic airspaces are seen in both lower lobes. Note the presence of ground-glass opacities

Table 5.5. Appearance and distribution patterns in pulmonary emphysema and cystic and cyst-like lung disease.

	Appearance	Distribution	Remarks and associated findings
<b>EMPHYSEMA</b>			
Mild centrilobular emphysema	Multiple small lucencies without a wall	Upper lobe predominance; uneven distribution. Centrilobular; centrilobular arteriole may be visible	Smoking history
Advanced, confluent centrilobular emphysema	Irregular, confluent lucencies; walls can often be recognised	Upper lobe predominance; uneven distribution	Smoking history. Lung destruction is evident
Mild panlobular emphysema	Overall decrease in lung attenuation and size reduction of vessels	Generalised or lower lobe predominance	May be associated with alpha-1-antitrypsin deficiency. Sometimes difficult to differentiate from decreased perfusion (Table 5.3)
Advanced panlobular emphysema	Overall decrease in lung attenuation and size reduction of vessels with areas of evident lung destruction	Generalised or lower lobe predominance	May be associated with alpha-1-antitrypsin deficiency. Sometimes difficult to differentiate from advanced confluent emphysema (Table 5.3)
Paraseptal emphysema	Single layer of subpleural lucencies often with visible thin wall	Upper lobe predominance; subpleural location. Thin walls corresponding with interlobular septa	
Bullous emphysema	Large air-containing areas (1 cm to several centimetres). Thin wall	Predominantly subpleural; upper lobes. Often asymmetric	Bullae may increase progressively. Smokers and non-smokers Often associated with centrilobular and paraseptal emphysema

**Table 5.5.** Appearance and distribution patterns in pulmonary emphysema and cystic and cyst-like lung disease.

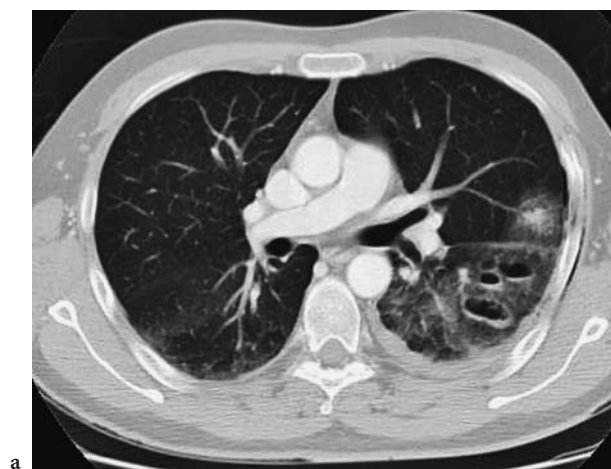
	Appearance	Distribution	Remarks and associated findings
<b>Cysts/Cyst-like</b>			
Advanced fibrosis. (Honeycombing)	Several layers of irregular cystic spaces (1 mm to a few centimetres). Irregular wall	Depends on initial lung disease. Subpleural lung and lung base in usual interstitial pneumonia (UIP)	Signs of lung distortion. Traction bronchiectasis
Lymphangiomyomatosis (LAM)	Thin-walled usually round cysts	Diffuse; costophrenic angles also involved	Almost exclusively in women. Pneumothorax may occur. May be seen in patients with tuberous sclerosis
Langerhans cell histiocytosis	Irregularly shaped, thin- and thick-walled cysts. Some cysts are confluent	Upper lobe predominance; costophrenic angles spared	Middle-aged male/female ratio = 1. Majority smokes. Centrilobular and peribronchiolar nodules (sometimes cavitory) often present. May progress to honeycombing
Lymphocytic interstitial pneumonia (LIP)	Thin-walled cystic airspaces (1–30 mm)	Cysts involve less than 10% of the lung	Ground-glass opacity and centrilobular nodules are predominant findings
Metastatic tumour	Sharply defined thin and thick-walled. Irregular inner border. Varying stage of cavitation	Diffuse. Lower lobe predominance. Peripheral	Feeding vessel sign may be present. Peripheral nodules
Septic embolism	Ill-defined thin- and thick-walled cavities; varying stage of cavitation. Irregular inner border. Halo sign	Diffuse. Lower lobe predominance. Peripheral	Feeding vessel sign may be present. Peripheral nodules and triangular opacities
Wegener's granulomatosis	Large cavities with a thick irregular and shaggy wall	No zone predominance	Consolidation, ground-glass and multiple nodules (a few millimetres to 10 cm) are predominant findings
Tuberculosis (TB)	Thin or thick-walled cavitation	Primary TB: middle and lower lobes. Postprimary TB: upper lobes	Consolidation, ground-glass, bronchial wall thickening, tree in bud
Pulmonary aspergillosis	Cavitory nodules and consolidation. Air-crescent sign. Halo sign	Upper lobes	Underlying chronic lung disease, immunosuppression. Consolidation, ground-glass, nodules, tree in bud
Pneumatocoeles in <i>Pneumocystis jiroveci</i> pneumonia	Thin-walled cysts. Thick-walled, irregular septated cavities	Upper lobes. Central, perihilar	Patchy or diffuse ground-glass opacity
Cystic bronchiectasis	Group or cluster of thin-walled cysts. Air-fluid levels	Patchy distribution	Look for the signet ring sign

greater than the diameter of the adjacent pulmonary artery branch, that is when the bronchus/artery (B/A) ratio is greater than 1 (NAIDICH et al. 1982). However, B/A ratios higher than 1 have been observed in normal subjects, especially in older people (MATSUOKA et al. 2003; PARK et al. 1997). In patients with bronchiectasis, the B/A ratio is often over 1.5, a finding that not only reflects the presence of bronchial dilatation but also some reduction in pulmonary artery diameter as a consequence of decreased lung perfusion, which is often seen in affected lung regions as a consequence of hypoventilation (KIM et al. 1997a).

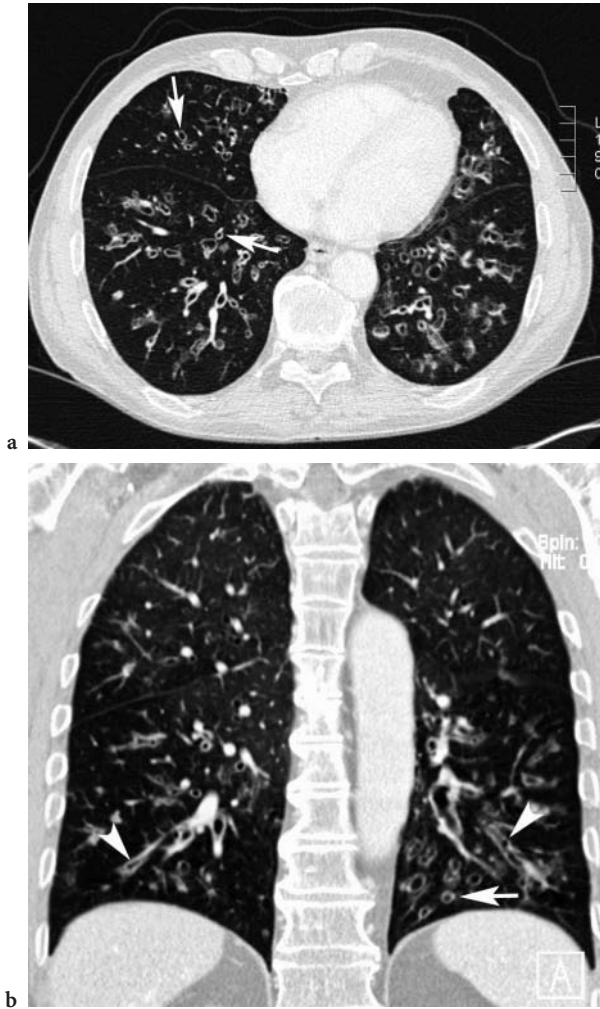


**Fig. 5.12.** Cavitary nodules in a patient with pulmonary metastases. Multiple thick-walled cyst-like structures are seen in both lungs. Note also the presence of nodular opacities

In most cases, dilated bronchi are easily recognised. When HRCT shows bronchi in the peripheral 1 cm of the lung, these bronchi are dilated and/or show wall thickening (KANG et al. 1995; KIM et al. 1997b). Bronchiectasis that is perpendicular to the scan plane can simulate cysts. However, the presence of an accompanying pulmonary artery branch producing the signet ring sign together with the fact that scrolling through the adjacent CT slices shows the tubular character of the abnormality can usually differentiate between both entities (NAIDICH et al. 1982) (Fig. 5.14). The differential diagnosis between lung cysts and cystic bronchiectasis may, however, sometimes be difficult because in this type of bronchiectasis, bronchial dilatation often appears as a group or cluster of air-filled cysts. The signs mentioned above can again be used for differential diagnosis but, in addition, cystic bronchiectasis is often patchy in distribution, while cystic lung disease such as lymphangiomyomatosis and Langerhans histiocytosis are often more diffuse (Table 5.5). Also, air-fluid levels, which may be present in bronchiectasis, are usually not seen in patients with lung cysts. Traction bronchiectasis is another type of bronchiectasis that is sometimes difficult to differentiate from cystic lung changes. Traction bronchiectasis is seen in patients with lung fibrosis and distortion of the lung architecture. Traction by fibrosis causes irregular dilatation of the bronchi, which is typically varicose in appearance (WEBB et



**Fig. 5.13a,b.** Pneumatocoele in association with post-traumatic pulmonary laceration. Thin-walled cystic lesions are seen in an area of lung consolidation and ground-glass opacity that are caused by pulmonary laceration and haemorrhage (Courtesy of Wim Volders, Department of Radiology, AZ Klina, Antwerp, Belgium)



**Fig. 5.14a,b.** Bronchiectasis that is perpendicular to the scan plane can simulate cysts. However, differentiation between the two entities is usually possible when an accompanying pulmonary artery branch producing the signet ring sign (arrows) is seen and when scrolling through the adjacent CT slices and looking at images in another reconstruction plane show the tubular character of the abnormality (arrowheads)

al. 1988; WESTCOTT and COLE 1986). Especially in honeycombing, the differential diagnosis between honeycomb cysts and traction bronchiectasis may be difficult and in fact both contribute to the cystic appearance of end-stage lung fibrosis seen on CT (NISHIMURA et al. 1992).

Table 5.4 shows a list of diseases or processes that are frequently associated with the development of cysts (ABBOTT et al. 2004; BRAUNER et al. 1997; DESAI et al. 1997; GAENSLER et al. 1991; HANCOCK and OSBORNE 2002; ICHIKAWA et al. 1994; JOHKOH

et al. 1999; LEE et al. 2002; LENOIR et al. 1990; MCGUINNESS and NAIDICH 2002; MOORE et al. 1989; MÜLLER et al. 1990; PRIMACK et al. 1993; RAPPAPORT et al. 1989; SHERRIER et al. 1989; TEMPLETON et al. 1989; TUDDENHAM 1984).

- Lung cysts are well defined, circumscribed and often rounded lesions with a thin wall composed of cellular elements that usually contain air
- The most frequent cause of lung cysts is advanced fibrosis (honeycomb cysts)
- Cavitory nodules are cyst-like structures that develop because necrosis occurs in pre-existing nodules
- Pneumatocoeles are thin-walled air-filled spaces occurring in association with some pulmonary infections and with post-traumatic pulmonary laceration
- Bronchiectasis can mimic lung cysts

## 5.2.4

### Pulmonary Emphysema

Pulmonary emphysema is defined as a permanent, abnormal enlargement of airspaces distal to the terminal bronchiole and accompanied by the destruction of the walls of the involved airspaces (NAIDICH 1991; SNIDER 1994; THURLBECK and MULLER 1994). This combination of tissue destruction and increased amount of air in the enlarged airspaces causes areas of decreased lung attenuation. The major difference between pulmonary emphysema, on one hand, and lung hypoattenuation caused by hypoperfusion, hypoattenuation as part of mosaic perfusion, and air trapping, on the other hand, is that in emphysema lung destruction is present, which usually can be recognised on CT. Table 5.3 lists the major CT features allowing to differentiate between these entities. The difference between emphysema and cystic lung changes is in most cases also obvious and is related to the study of the wall and the regional distribution of the changes (Table 5.5). However, sometimes emphysematous changes may still mimic lung cysts or honeycombing.

The CT diagnosis of pulmonary emphysema is based on the recognition of focal areas of very low attenuation that can be easily contrasted with



surrounding (higher attenuation) normal lung (HRUBAN et al. 1987; MILLER et al. 1989; MÜLLER et al. 1988; SANDERS et al. 1988). Although in some types of emphysema these areas of very low attenuation can have a wall, which is visible on CT, a wall is usually not present or hardly visible. As is shown in Table 5.5 and as will be discussed in Sect. 5.3, based on the study of the appearance and on the distribution pattern, it is possible in many patients to classify the type of emphysema.

In general, emphysema has three major forms of presentation:

- Multiple small centrilobular lucencies without walls or with occasionally visible walls (Fig. 5.15). When disease progresses, the lucencies become

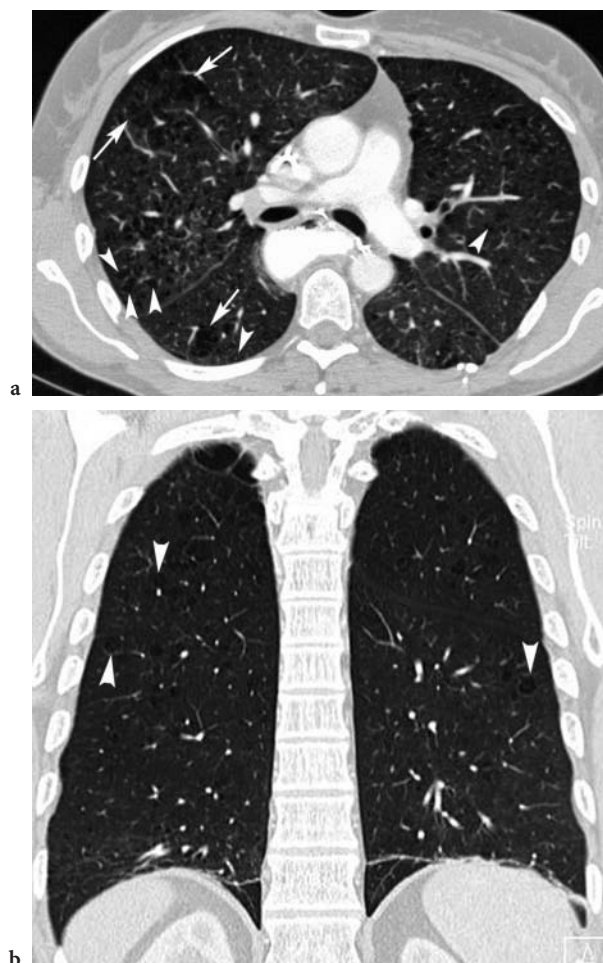


Fig. 5.15a,b. Mild centrilobular emphysema. Multiple small lucencies without walls or with barely visible walls are seen in both lungs. The centrilobular localisation can be appreciated in some lucencies by the presence of a small dot at the centre representing the centrilobular artery (arrowheads). Note that some lucencies merge together (arrows)

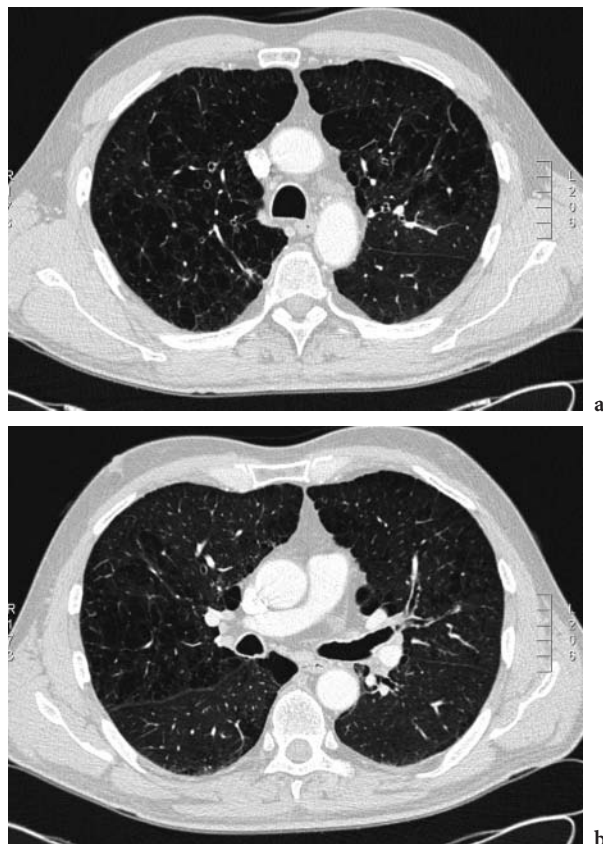
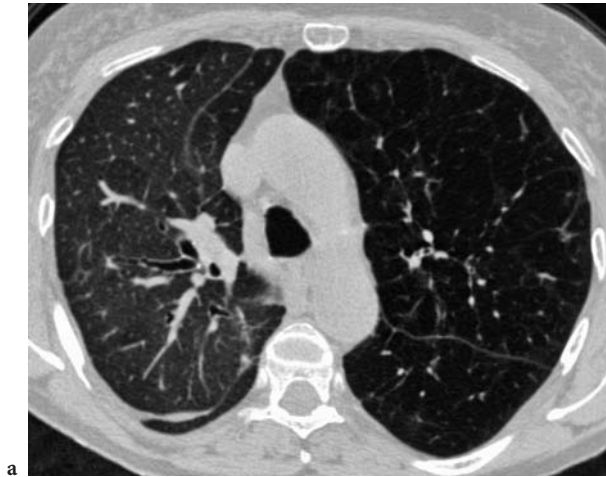


Fig. 5.16a,b. Confluent centrilobular emphysema. Multiple, confluent lucencies, some with recognisable wall, are seen in the upper part of both lungs

confluent and lung destruction is usually more evident while walls can often be recognised (Figs. 5.15–5.17). This presentation is predominantly seen in centrilobular (proximal or centriacinar) and paraseptal (distal acinar) emphysema (Fig. 5.18).

- An overall decrease in lung attenuation and a reduction in the size of pulmonary vessels (Fig. 5.19). This presentation is predominantly seen in panlobular (panacinar) emphysema and should be differentiated from reduced lung attenuation caused by hypoperfusion, i.e. without lung destruction (Table 5.3). When this type of emphysema is more advanced, lung destruction usually also becomes more evident and differential diagnosis with hypoperfusion secondary to small airway involvement or vascular narrowing is also easier (Fig. 5.20).
- Large air-containing areas, with a diameter larger than 1 cm and up to several centimetres, that usually have a thin and smooth epithelialised wall





a



b



c

**Fig. 5.17a–c.** Severe confluent centrilobular emphysema: (a) and (b) axial and (c) coronal view in a patient who underwent a right lung transplantation. Multiple irregular and confluent lucencies are seen in the left lung. Note the upper lobe dominance and the obvious signs of lung distortion and lung destruction. The latter are more pronounced than in panlobular emphysema (Figs. 5.19 and 5.20)

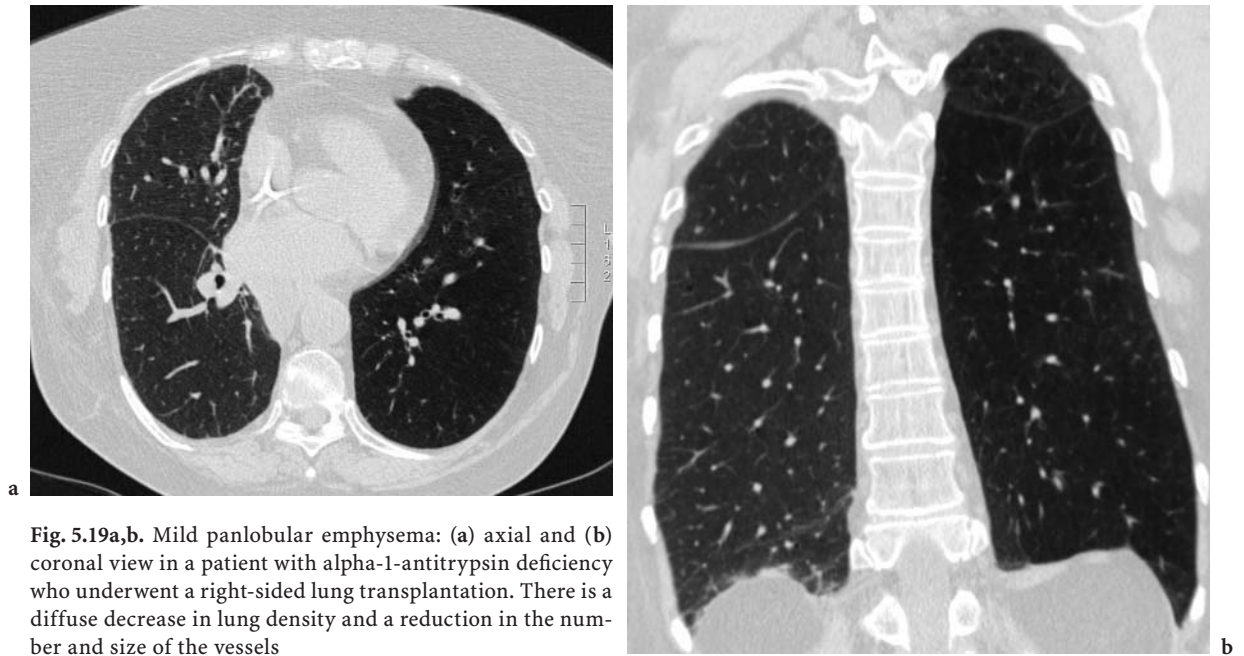


a

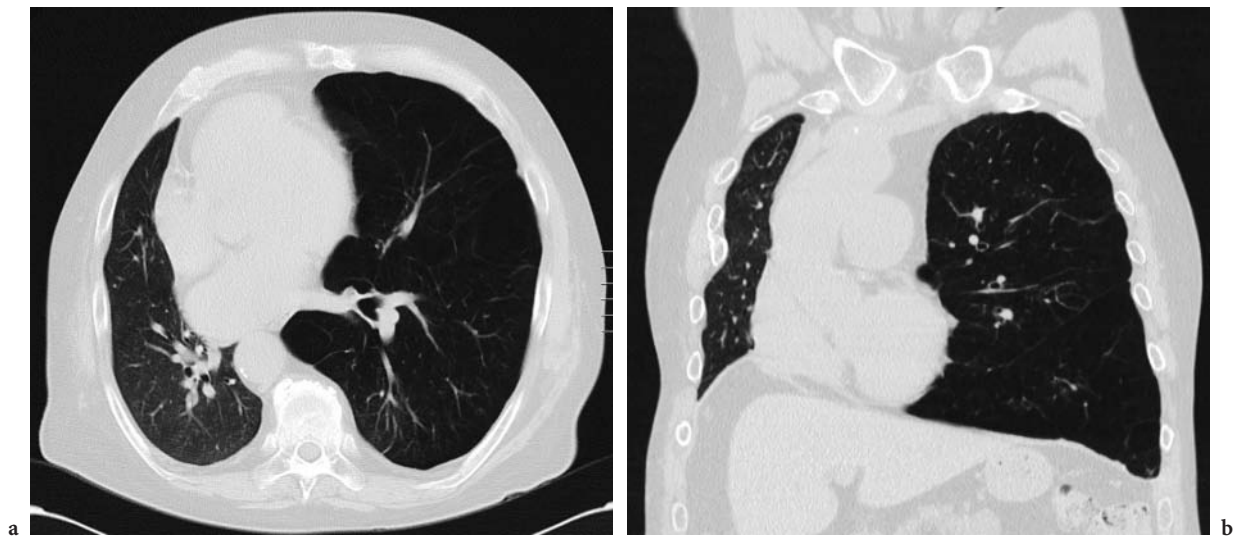


b

**Fig. 5.18a,b.** Paraseptal emphysema: (a) axial and (b) coronal view. A single layer of subpleural lucencies with a thin wall is seen in the left upper lung. Note also the presence of mild centrilobular emphysema in both lungs and confluent centrilobular emphysema in the right upper lobe



**Fig. 5.19a,b.** Mild panlobular emphysema: (a) axial and (b) coronal view in a patient with alpha-1-antitrypsin deficiency who underwent a right-sided lung transplantation. There is a diffuse decrease in lung density and a reduction in the number and size of the vessels



**Fig. 5.20a,b.** Panlobular emphysema: (a) axial and (b) coronal view in a patient with alpha-1-antitrypsin deficiency who underwent a right-sided lung transplantation. There is a diffuse decrease in lung density and a reduction in the number and size of the vessels in the lower lobe of the left lung. Note that there is more lung destruction and lung distortion than in the patient shown in Fig. 5.19, making differential diagnosis with severe confluent centrilobular emphysema (Fig. 5.17) more difficult

that is usually no thicker than 1 mm (Fig. 5.21). These areas are called bullae and are often associated with centrilobular and paraseptal emphysema. When this is the case and when bullae are a dominant finding, the term “bullous emphysema” is used (AUSTIN et al. 1996; STERN et al. 1994b; TUDDENHAM 1984) (Fig. 5.21). The term “bleb”

is sometimes used pathologically to refer to a gas-containing space within the visceral pleura (TUDDENHAM 1984). From a radiological and practical point of view, the distinction between bulla and bleb is not significant and the term “bulla” is preferred. Bullae can sometimes mimic cystic lung changes.



**Fig. 5.21a,b.** Bullous emphysema. Several large air-containing areas with a diameter larger than 1 cm are seen in both lungs. Note the subpleural location and the upper lobe predominance

An additional type of lung destruction can develop in areas of pulmonary fibrosis. This type of emphysema is usually referred to as paracicatricial or irregular emphysema (SNIDER 1994)

- Pulmonary emphysema combines a permanent abnormal enlargement of airspaces distal to the terminal bronchioles and a destruction of the walls of these involved airspaces
- Emphysema has three major forms of presentation
  - Small lucencies that can become confluent to form large irregular areas of very low density (often with a wall) with clear signs of lung destruction
  - An overall decrease in lung attenuation with a reduction of vascular markings
  - Large air-containing areas with a diameter of larger than 1 cm: bullae

### 5.3

#### Distribution Patterns and Diagnostic Algorithm

Study of the distribution patterns in low-attenuation lung disease is predominantly a study of the regional distribution of the diseases (Table 5.6). This

is in contrast to the nodular and the linear pattern where diagnosis is also, and often predominantly, based on the decision of whether the disease shows a lymphatic, a bronchial or a vascular distribution or whether the disease is predominantly located in the interstitium or predominantly involving the airspace. Hence, relating the low-attenuation abnormalities with the components of the secondary pulmonary lobule is of less value to the diagnosis in most cases.

The first question that should be raised when reading a CT scan of the lungs showing low-attenuation lung disease is whether the low-attenuation area has obvious signs of lung destruction/distortion (Fig. 5.22).

When no signs of lung destruction or distortion are present and especially when the calibre of the vascular structures in the low attenuation area(s) is also decreased, the area(s) is/are very likely the result of decreased blood supply or hypoperfusion (Fig. 5.22a). Table 5.3 shows the signs that can be helpful to differentiate between decreased lung perfusion and lung destruction caused by emphysema. Areas of decreased lung perfusion can be large corresponding with lobes or even with an entire lung (Fig. 5.2), but they are often small and in that case correspond to one or a few adjacent secondary pulmonary lobules or with a lung segment (LYNCH et al. 1990; MARTI-BONMATI et al. 1989; WEBB 1994) (Fig. 5.3). They can be anywhere in the lung but are often found in the lung periphery and often in the dependent parts of the lower lobes.



**Table 5.6.** Regional distribution of lung diseases that can cause decreased lung attenuation.

Upper lung vs lower lung vs diffuse
<ul style="list-style-type: none"> <li>● <b>Upper:</b> Langerhans cell histiocytosis, sarcoidosis, silicosis and coal workers' pneumoconiosis, tuberculosis, cystic fibrosis, centrilobular emphysema, paraseptal emphysema</li> <li>● <b>Lower:</b> usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), haematogenous metastases, panlobular emphysema</li> <li>● <b>Diffuse:</b> lymphangiomyomatosis, haematogenous metastases</li> </ul>
Central lung vs peripheral lung
<ul style="list-style-type: none"> <li>● <b>Central:</b> silicosis and coal workers' pneumoconiosis, large airway disease</li> <li>● <b>Peripheral:</b> usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), haematogenous metastases, septic emboli, small airway disease, small vessel narrowing and obstruction</li> </ul>
Posterior lung vs anterior lung
<ul style="list-style-type: none"> <li>● <b>Posterior:</b> usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), silicosis and coal workers' pneumoconiosis</li> <li>● <b>Anterior:</b> post-adult respiratory distress (ARDS) fibrosis</li> </ul>
Can be unilateral or asymmetric
<ul style="list-style-type: none"> <li>● Centrilobular emphysema</li> </ul>

This is especially true for the mosaic perfusion pattern (Fig. 5.3). Widespread areas of hypoperfusion can rarely be idiopathic but are more frequently the result of lung diseases such as connective tissue disease, transplantation-associated airway injury, idiopathic pulmonary hypertension and occlusive vasculopathy (ARAKAWA and WEBB 1998b; BERGIN et al. 1996; SCHWICKERT et al. 1994; WEBB 1997; WORTHY et al. 1997b) (Table 5.1). Patchy areas of hypoperfusion surrounded by areas of increased perfusion (mosaic perfusion) are the hallmark of constrictive bronchiolitis (bronchiolitis obliterans) but can be seen in other diseases that either indirectly (by first narrowing the small airways) or

directly (by directly obstructing the small arteries) cause patchy areas of hypoperfusion (Table 5.1). As mentioned earlier, expiratory CT may or may not accentuate these areas of decreased attenuation. This accentuation is the result of the increase in lung density in the normal lung areas, which after expiration contain less air, and the continuing decreased lung density in the lung areas that show hypoperfusion. This phenomenon of air trapping very strongly suggests that the cause of the mosaic perfusion is related to airway disease, i.e. the disease has an airway distribution (RINGERTZ et al. 1989; STERN and WEBB 1993). The presence of abnormal thick-walled and sometimes dilated airways is another argument in favour of this. However, when there is no accentuation of the area(s) of decreased attenuation on the expiratory CT, i.e. when there is no air trapping, a vascular distribution of disease is very likely. The combination of mosaic perfusion not accentuated on expiratory CT and enlargement of the main pulmonary arteries because of pulmonary hypertension very strongly suggest chronic pulmonary embolism (ARAKAWA et al. 1998; ARAKAWA and WEBB 1998a; CHEN et al. 1998). It should be emphasised again that air trapping might be visible on the expiratory CT while the inspiratory CT does not show obvious mosaic perfusion. When limited to one or a few (adjacent) pulmonary lobules, this usually has no influence on pulmonary function, but when extensive it indicates again the presence of airway obstruction (LEE et al. 2000; VERSCHAKELLEN et al. 1998).

If distortion/destruction is obvious or suspected, it should be decided whether the lung changes are caused either by cystic lung disease or by pulmonary emphysema (Fig. 5.22b). This differential diagnosis is based on the study of both the appearance and the distribution patterns (HRUBAN et al. 1987; ICHIKAWA et al. 1994; JOHKOH et al. 1999; MILLER et al. 1989; MOORE et al. 1989; MÜLLER et al. 1988; SANDERS et al. 1988; TUDDENHAM 1984). Table 5.5 gives an overview of these patterns in emphysema and in most cystic lung diseases. In general in centrilobular pulmonary emphysema, well-defined areas of extreme low density are seen, which have no wall and predominantly involve the upper lobes, which are located in the centre of the secondary pulmonary lobule in early disease and can have a thin wall and become confluent in more extensive disease. In severe centrilobular emphysema, the most striking finding is lung destruction, whereas in paraseptal emphysema the peripheral subpleural localisation is

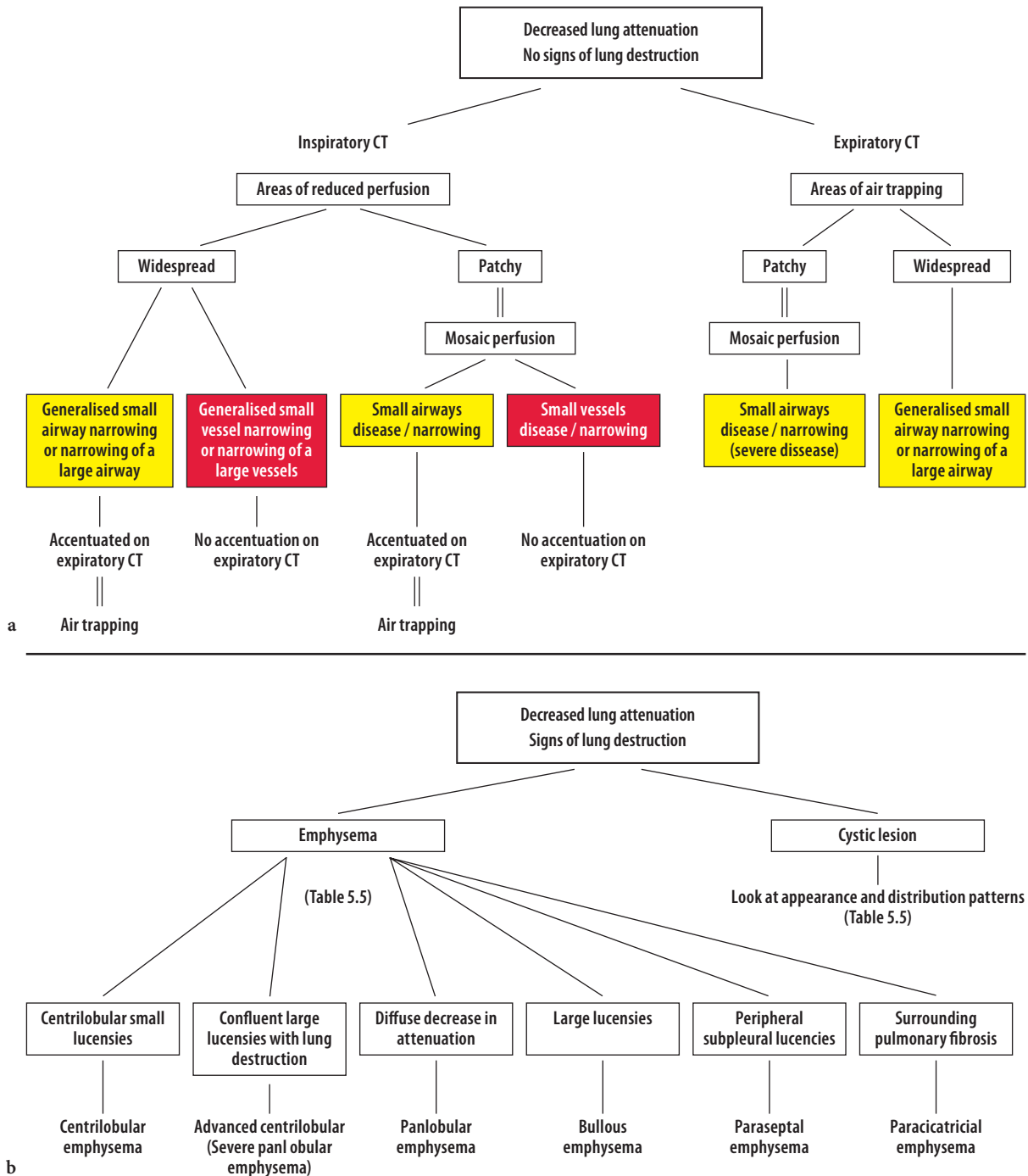


Fig. 5.22a,b. Decreased lung attenuation: diagnostic algorithm

the most striking finding. The diagnosis of panlobular emphysema is based on recognising a diffuse decrease in attenuation and a reduction in the size of the pulmonary vessels in the lower lung, which can be difficult especially if there are no normal lung areas to compare with. Panlobular emphysema should

also be differentiated from decreased lung perfusion (Table 5.3). A clinical history of alpha-1-antitrypsin deficiency is of course very helpful. Emphysema is termed paracatricial or irregular when it is caused by and surrounds an area of pulmonary fibrosis. Cysts usually have a wall, which can be thin but is



often thick and irregular, particularly in the case of cavitary nodules. Differential diagnosis is also based on the study of the appearance and distribution patterns (Table 5.5).

Finally, it is important to differentiate between honeycombing and paraseptal emphysema. This differential diagnosis is based on the study of the appearance pattern (several layers of irregular and subpleural cystic spaces with an irregular wall in honeycombing vs a single layer of subpleural lucencies with a thin and regular wall in paraseptal emphysema) and the regional distribution pattern (upper lobes in paraseptal emphysema vs lower lobes in honeycombing).

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# Nodular Pattern

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## 6.1

### Introduction

The nodular pattern is characterised by the presence of multiple nodular opacities with a maximum diameter of 3 cm. A nodule with a diameter less than 1 cm can be defined as a small nodule, whereas a nodule larger than 1 cm is often called a large nodule (GRENIER et al. 1991). The term “micronodule” usually refers to nodules no larger than 7 mm in diameter (AUSTIN et al. 1996; COLLINS 2001). The term “miliary pattern” indicates the presence of multiple small (1–3 mm) micronodules with sharp contours distributed in a major part of the lungs (ANDREU et al. 2002; LEE et al. 1999). Generally, the nodules in the nodular pattern range from 1 mm to 1 cm. Larger nodules are often the result of the fusion of several small nodules.

The CT assessment of the nodular pattern is based on the assessment of the nodule characteristics (appearance pattern) and on the study of the distribution of the nodules (distribution pattern). The assessment of nodule characteristics is predominantly based on the study of the borders (sharp or blurred) and the density (solid or ground-glass) of these nodules. Using these characteristics, lung nodules can often be divided into interstitial nodules and airspace nodules (Table 6.1). Other characteristics such as size, cavitation and presence of calcium are, of course, valuable also (MULLER et al. 2003a–d; TSUCHIYA 2005). Since histologically many nodular opacities involve both the interstitial and alveolar compartments, the distinction between airspace nodules and interstitial nodules is somewhat arbitrary and often difficult to make (PATTI et al. 2004). Hence, the study of the distribution of the nodules is generally more valuable in the differential diagnosis than their appearance. This study includes the consideration of the regional distribution (upper lung vs lower lung vs diffuse; central vs peripheral; posterior vs anterior) and, most importantly, the characterisation of the nodules by their relation to the secondary pulmonary lobule. The latter allows the distinction between the (peri)lymphatic nodular pattern, the centrilobular nodular pattern and the nodular pattern with random distribution (COLBY and SWENSEN 1996; RAOOF et al. 2006).

**Table 6.1.** Interstitial and airspace nodules

Appearance/attenuation	Well defined	Ill defined
Soft tissue opacity	Interstitial nodule Airspace nodule	Airspace nodule
Ground-glass opacity	Interstitial nodule Airspace nodule	Airspace nodule



## 6.2

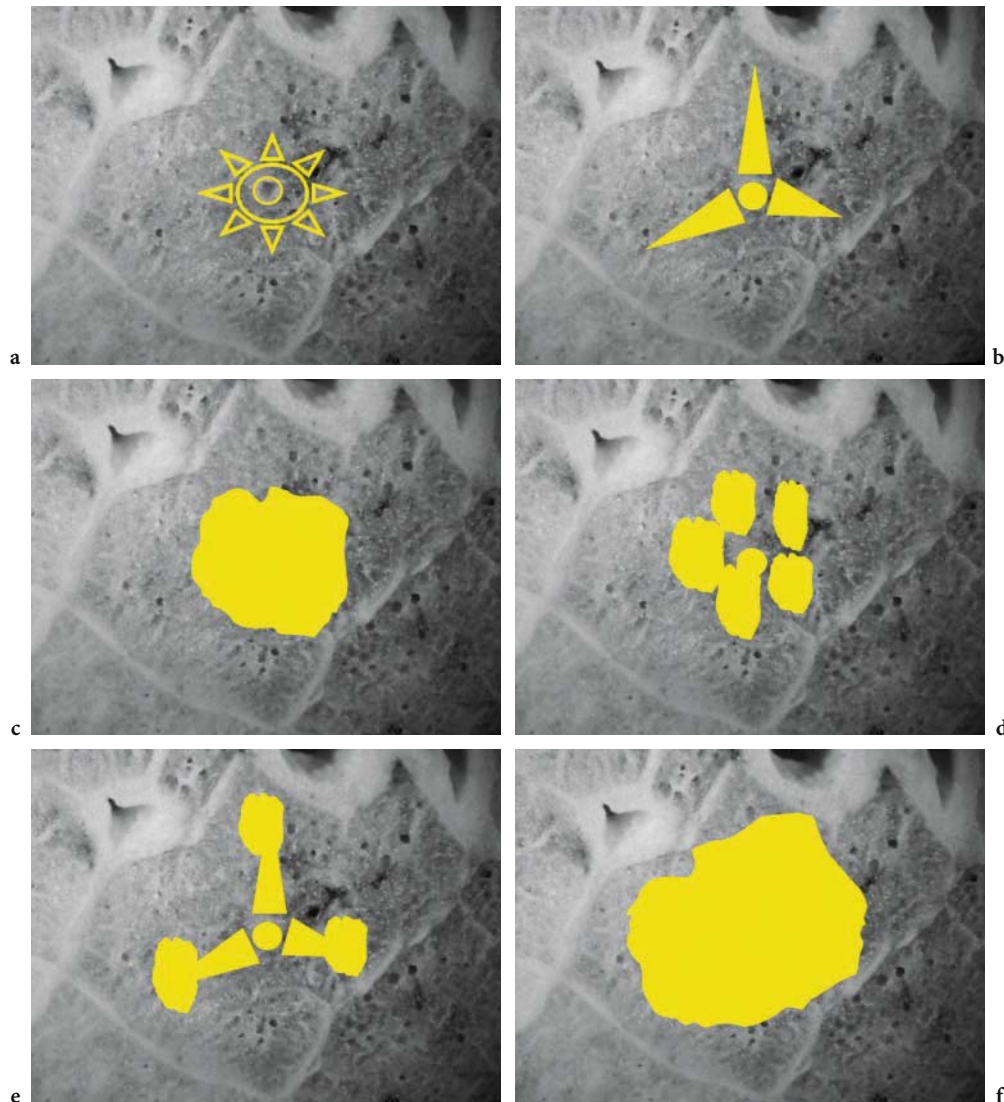
### Types of Nodular Opacities

#### 6.2.1

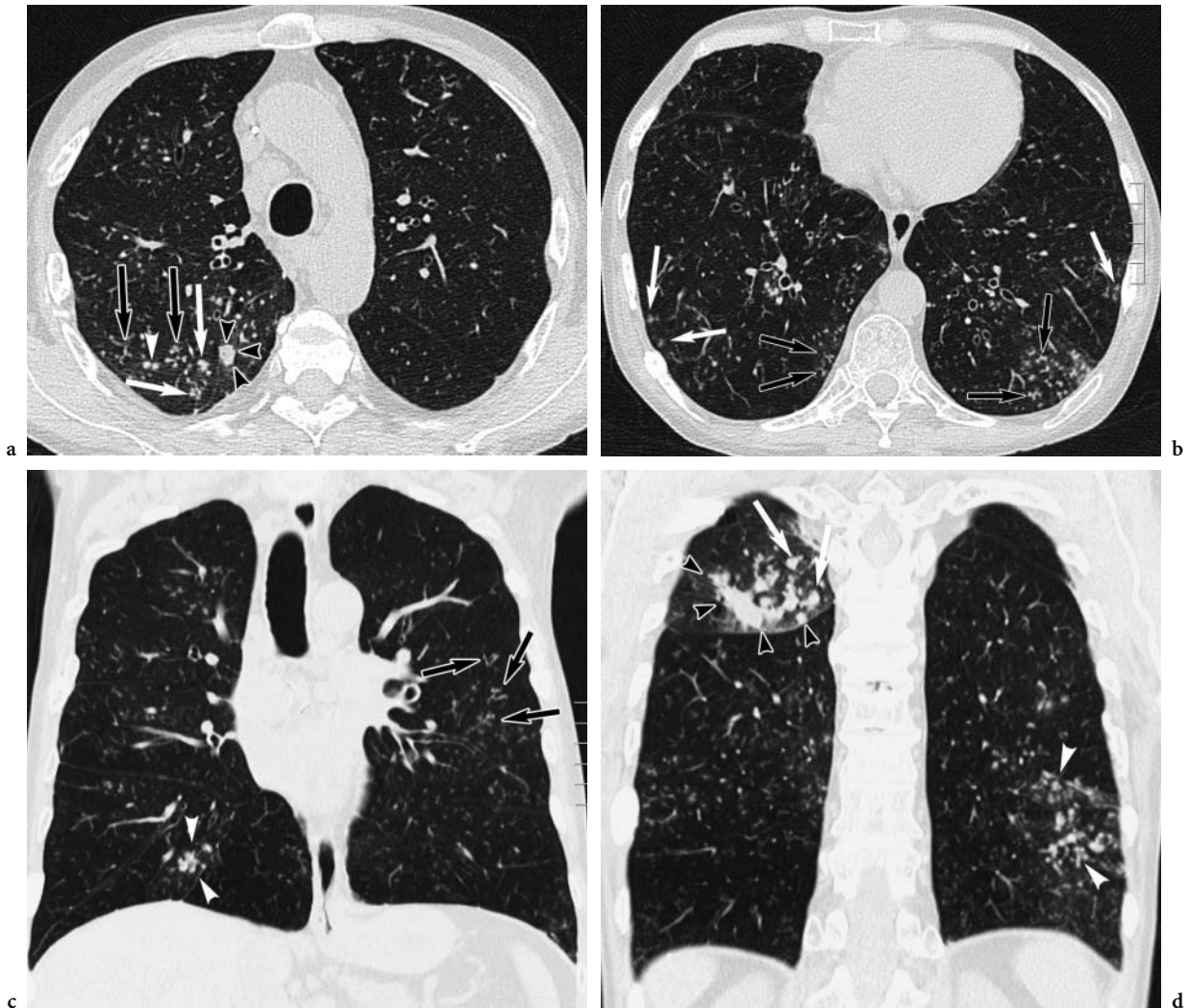
##### Airspace Nodules

Airspace nodules may develop when the air in the (dilated) small centrilobular airways and in a small, more or less circumscribed area of the lung airspace surrounding these airways is replaced by fluid or cells or by a combination of both, a process

that is usually associated with some (inflammatory) thickening of the airway and airspace wall. The nodular character of these areas of increased density can be understood if one looks at the relationship between the anatomy of the secondary pulmonary lobule and the distribution pattern of diseases that can cause these airspace nodules. Since the terminal bronchioles are distributed to the central core of the secondary pulmonary lobule, processes that show an airway distribution will involve the terminal airways at the centre of the lobule and spread out to the periphery (Fig. 6.1a).



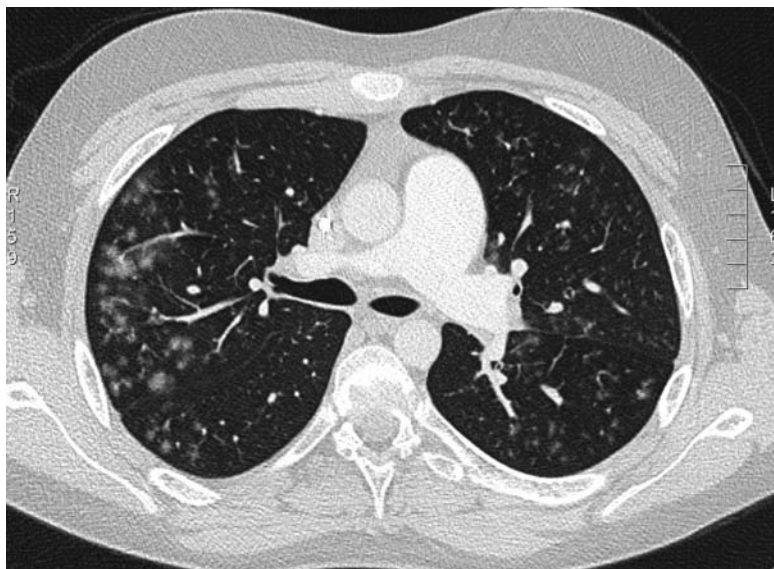
**Fig. 6.1a–f.** Processes that show an airway distribution will involve the terminal airways at the centre of the lobule and spread out to the periphery (a). Filling of the usually dilated small airways by fluid (mucus, pus) and/or cells and the peribronchiolar inflammation involving the surrounding airspaces can cause the appearance of centrilobular branching lines (b), centrilobular airspace nodules (c) or a rosette of small nodules (d) and a tree-in-bud pattern (e). When the process of airspace filling progresses, the entire secondary pulmonary lobule can become opacified (f)



**Fig. 6.2a–d.** Infectious bronchitis and bronchiolitis with centrilobular airspace nodules with soft tissue density (*white arrows*), clusters or rosettes of small nodules (*white arrowheads*), centrilobular branching lines and tree-in-bud patterns (*black arrows*). Growing and merging of these airspace nodules causes the appearance of larger nodular opacities that can reach the interlobular septa and pleura and even irregular nodular masses (*black arrowheads*). Note the bronchial wall thickening indicating that the bronchi are also involved

The replacement of the air in the, usually dilated, small airways by fluid (mucus, pus) and/or cells and the peribronchiolar inflammation involving the surrounding airspaces, also filling them with fluid and cells, will cause the appearance of centrilobular branching lines (see Sect 7.2.2.2 in Chap. 7) (Figs. 6.1b and 6.2a–c) and nodular opacities (Figs. 6.1c,d and 6.2a,b,d). These nodular opacities are seen on CT, not only because the branching lines are cut across, but also because the peribronchiolar airspaces get involved, a process that progresses from the centre to the periphery of the secondary pulmonary lobule. This explains

why airspace nodules can present not only as small centrilobular nodular opacities but also as a cluster or rosette of small nodules (Figs. 6.1d and 6.2a,c,d), which are initially also located near the centre of the secondary pulmonary lobule but can grow and merge together to larger nodules that may involve almost the entire secondary pulmonary lobule. When centrilobular nodules are present together with intralobular branching lines, a pattern occurs that has been likened to a budding or fruiting tree: the tree-in-bud-pattern (AKIRA et al. 1988; IM et al. 1993; RAOOF et al. 2006) (see Sect. 6.3.3) (Figs. 6.1e and 6.2a–c).



**Fig. 6.3.** Infectious bronchiolitis. Multiple airspace nodules are seen in both upper lung areas, predominantly in the right upper lobe. Most nodules have a ground-glass density

Depending on the cause and the degree of involvement, the airspace nodules can have a ground-glass density (Fig. 6.3) or a soft tissue density (Fig. 6.2) obscuring the vessels. They can be sharply defined but are usually ill defined (ITO et al. 1978; MURATA et al. 1986, 1989; NAIDICH et al. 1985; RAOOF et al. 2006; WEBB 1989; XIA et al. 2002).

When the process of airspace filling progresses, the entire secondary pulmonary lobule can be opacified at some point (Fig. 6.1f). When this happens also in adjacent secondary pulmonary lobules, large nodules and masses can appear and even large areas of ground-glass opacity and lung consolidation can develop (see Chap. 4). Table 6.2 shows the different diseases that can be responsible for the development of airspace nodules. The diseases showing larger conglomerate nodules and masses are also indicated.

**Table 6.2.** Differential diagnosis of airspace nodules

- Infectious bronchiolitis and bronchopneumonia (viral, mycoplasma, aspergillus (including angioinvasive and bronchoinvasive aspergillosis), bacterial, tuberculosis)<sup>a</sup> (most frequent cause)
- Aspiration
- Cystic fibrosis
- Allergic bronchopulmonary aspergillosis
- Smoking related parenchymal lung disease (respiratory bronchiolitis interstitial lung disease (RB-ILD))
- Hypersensitivity pneumonitis
- Organising pneumonia<sup>a</sup>
- Bronchioloalveolar carcinoma<sup>a</sup>
- Pulmonary oedema
- Pulmonary haemorrhage

<sup>a</sup> May show conglomerate nodules or masses



- Airspace nodules are usually caused by a replacement of alveolar air by fluid and/or cells
- Airspace nodules can have a soft tissue density or a ground-glass density and can be sharply defined but are usually ill defined
- Airspace nodules are mostly located near the centre of the secondary pulmonary lobule but can, when disease progresses, involve the entire lobule
- Airspace nodules can be grouped in a cluster or rosette and when associated with the presence of intralobular branching lines can create the tree-in-bud pattern
- Merging of airspace nodules can be responsible for the development of larger nodules and areas of ground-glass opacity and lung consolidation

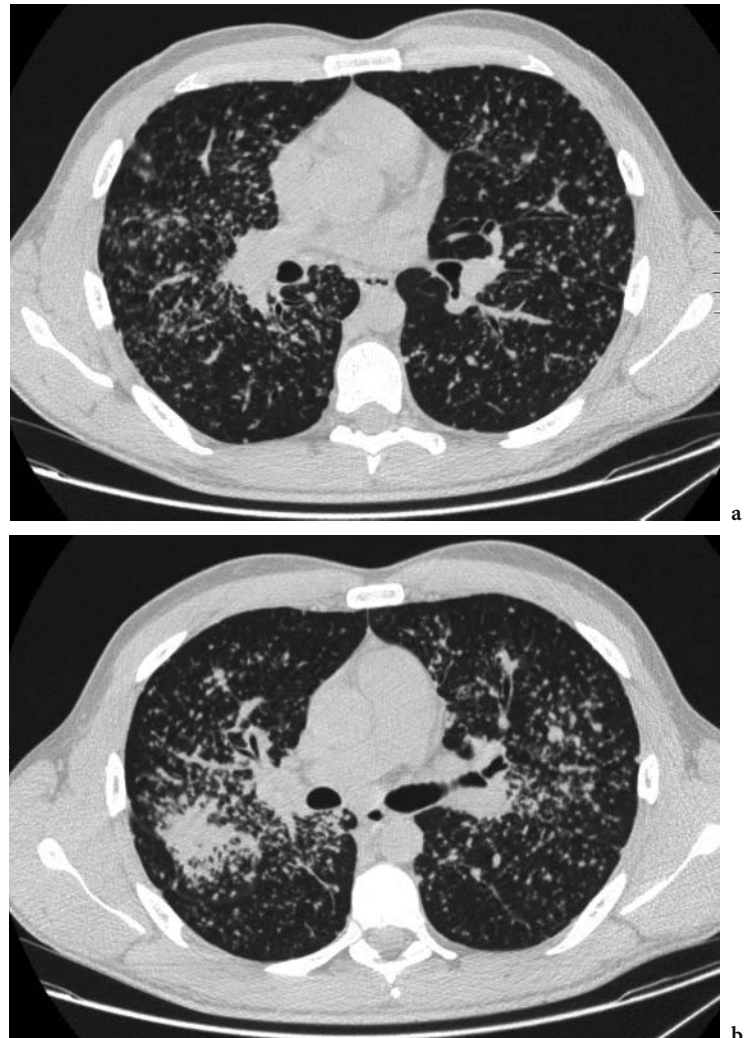


### 6.2.2

#### Interstitial Nodules

In contrast to airspace nodules, interstitial nodules are usually sharply defined. They also usually appear to be of soft tissue attenuation, obscuring the edges of vessels or other structures that they touch (Fig. 6.4), although sometimes they have a ground-glass density (BÉGIN et al. 1987; BERGIN et al. 1987, 1989; BRAUNER et al. 1992; NISHIMURA et al. 1993). Interstitial nodules can be located anywhere in the interstitium: the axial peribronchovascular and the centrilobular interstitium, the peripheral interstitium (subpleural space, interlobular septa and intra-lobular septa) and even in the parenchymal interstitium. Interstitial nodules are usually the result of a

nodular cellular proliferation and can be related to diseases that show a vascular or a (peri)lymphatic distribution, although in diseases like Langerhans cell histiocytosis (Fig. 6.11) and diffuse and interstitial lung diseases with a component of small airway involvement (follicular bronchiolitis in rheumatoid arthritis or Sjögren syndrome, panbronchiolitis, and early asbestosis), the nodules are located in or near the walls of the small airways. Conglomeration of interstitial nodules and growth of the nodules can result in the development of larger nodules and even masses (Fig. 6.4b). Table 6.3 shows the different diseases that can be responsible for the development of interstitial nodules. The diseases that can show larger conglomerate nodules and masses are also indicated.



**Fig. 6.4a,b.** (Peri)lymphatic distribution of interstitial nodules in a patient with sarcoidosis. The nodules are sharply defined and have a soft tissue density. In the upper lobes, conglomeration of these interstitial nodules has resulted in the development of larger nodules and masses (b)



Table 6.3. Differential diagnosis of interstitial nodules

- Sarcoidosis<sup>a</sup>
- Lymphangitic spread of tumour
- Lymphoproliferative disease<sup>a</sup>: lymphoma, lymphocytic interstitial pneumonia [LIP]
- Silicosis and coal workers' pneumoconiosis<sup>a</sup>
- Amyloidosis<sup>a</sup>
- Langerhans cell histiocytosis<sup>a</sup>
- Follicular bronchiolitis (rheumatoid arthritis [RA], Sjögren disease, AIDS)
- Panbronchiolitis
- Early asbestosis
- Haematogenous metastases<sup>a</sup>
- Vasculitis (Wegener's granulomatosis, Churg-Strauss syndrome)<sup>a</sup>
- Miliary infection (tuberculosis, fungus)
- Metastatic calcification

<sup>a</sup> May show (conglomerate) nodules or masses



- Interstitial nodules are usually caused by a nodular cellular proliferation in the interstitium.
- Interstitial nodules are mostly sharply defined and have in most cases a soft-tissue attenuation.
- Most interstitial nodules are related to diseases that show a vascular or a (peri)lymphatic distribution, although some of them are located in the interstitial tissue of bronchiolar walls.
- Conglomeration of interstitial nodules can cause larger nodules and masses.

### 6.2.3

#### Nodules with a Density Greater than Soft Tissue

Nodular opacities can show a partial or a diffuse increase in density, which usually results from the deposition of calcium in the nodule. Less frequently, the greater than soft tissue density is caused by deposition of other high-attenuation material such as talc, amiodarone, iron, mercury, acrylic cement and barium sulphate (BROWN et al. 1994) (Fig. 6.5).



Fig. 6.5. High-density nodules in the right lung (arrows) caused by acrylic cement embolism as a complication of percutaneous vertebroplasty



Fig. 6.6. High-density centrilobular nodules and rosettes of nodules in a patient with pulmonary haemorrhage

Calcification is most commonly secondary to dystrophic calcification in previously damaged lung parenchyma. Causes include infections, metastatic pulmonary calcifications, chronic haemorrhagic conditions (haemosiderosis) (Fig. 6.6), occupational diseases, deposition diseases, idiopathic disorders such as pulmonary alveolar microlithiasis, calcified pulmonary metastases, amyloidosis (Fig. 4.18), and progressive massive fibrosis (CHAN et al. 2002; CLUZEL et al. 1991; COTTON et al. 1998; MAILE et al. 1982; MARCHIORI et al. 2005; URBAN et al. 1993; WARD et al. 2000). In case of infectious cause or in patients with occupational lung disease, associated calcifications in hilar and mediastinal adenopathy are often found; these can show an egg-shell configuration in occupational lung disease (CHAN et al. 2002). Table 6.4 lists the most common causes of high-density lung nodules.

**Table 6.4.** Diseases than can show nodules with a density greater than soft tissue

Calcified small nodules
<ul style="list-style-type: none"> <li>● Postinfectious (calcified or partially calcified interstitial nodules): healed miliary tuberculosis, healed histoplasmosis, varicella (chickenpox) pneumonia</li> <li>● Metastatic pulmonary conditions (calcified or partially calcified centrilobular nodular opacities mimicking airspace nodules): hyperparathyroidism, chronic renal failure, sarcoidosis, multiple myeloma, massive osteolysis caused by metastases</li> <li>● Chronic haemorrhagic conditions (dense centrilobular airspace nodules): idiopathic pulmonary haemosiderosis, mitral stenosis</li> <li>● Occupational diseases (calcified or partially calcified interstitial nodules): silicosis, coal workers' pneumoconiosis</li> <li>● Pulmonary alveolar microlithiasis</li> </ul>
Noncalcified small nodules
<ul style="list-style-type: none"> <li>● Talcosis (very small interstitial nodules or ground-glass opacity)</li> <li>● Acrylic cement embolism (small metallic density nodules)</li> </ul>
Calcified large nodules
<ul style="list-style-type: none"> <li>● Pulmonary metastases (calcified or partially calcified large nodules) osteosarcoma, chondrosarcoma, synovial sarcoma, mucin-producing carcinoma, adenocarcinoma, thyroid tumours</li> <li>● Amyloidosis (calcified or partially calcified large nodules)</li> <li>● Progressive massive fibrosis (calcified or partially calcified masses)</li> </ul>

## 6.3

### Distribution Patterns and Diagnostic Algorithm

Although CT may not easily differentiate between interstitial and airspace nodules, when successful such a distinction is not only the first step to the differential diagnosis but is also helpful to determine the distribution pattern. As mentioned in the previous section, airspace nodules are predominantly caused by diseases that show an airway distribution and involve the airways and surrounding airspaces, while interstitial nodules are predominantly the re-

sult of diseases that are spread by the lymphatics or located in and around the lymphatics and diseases that are spread by the blood vessels. In fact, most diffuse and interstitial lung diseases that are located in the interstitium and not related to the lymphatics rarely cause a nodular pattern but mostly produce a linear pattern.

Hence, determining the distribution of the nodular pattern is predominantly based on the decision of whether the nodules show a (peri)lymphatic distribution, an airway distribution or a vascular distribution.

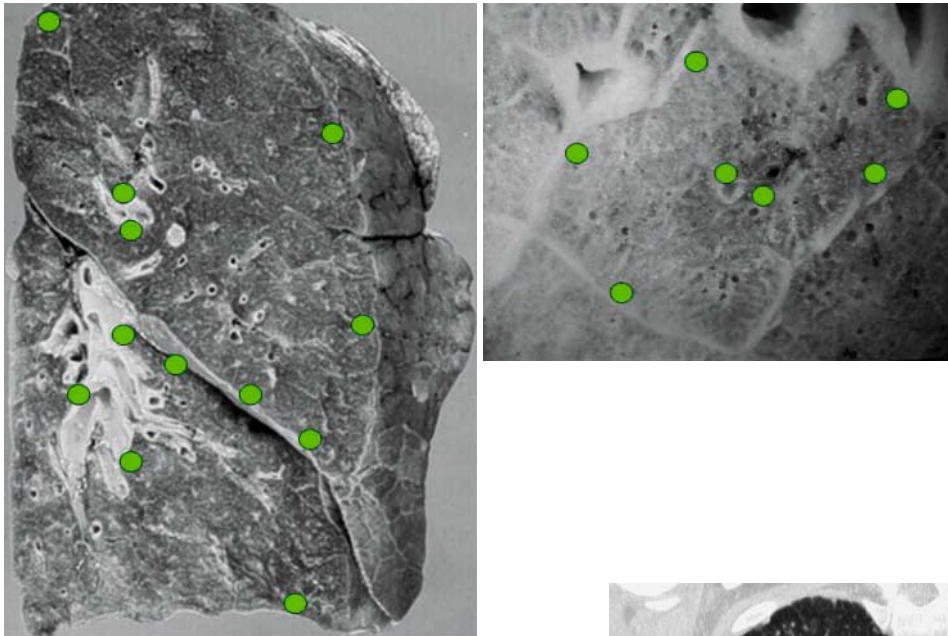
#### 6.3.1

##### (Peri)lymphatic Distribution

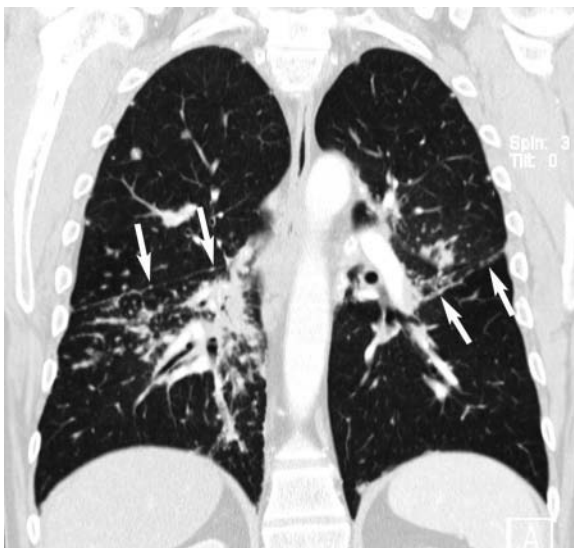
Lymphatics are found in the axial peribronchovascular connective tissue, the connective tissues around the centrilobular bronchioles and arteries, the interlobular septa and the subpleural connective tissue. Hence, a nodular pattern with (peri)lymphatic distribution typically shows peribronchovascular nodules, subpleural nodules, nodules in the interlobular septa and centrilobular nodules (COLBY and SWENSEN 1996; REMY-JARDIN et al. 1990) (Figs. 6.4 and 6.7). Since no lymphatics are present distal to the respiratory bronchioles, no nodules are seen between the core of the secondary pulmonary and the interlobular septa.

These interstitial nodules are mostly well defined, are of soft tissue attenuation and show a patchy distribution. They are most easily diagnosed when the nodules are in a subpleural location, particularly in relation to the fissures, where they can be distinguished from pulmonary vessels (Fig. 6.8).

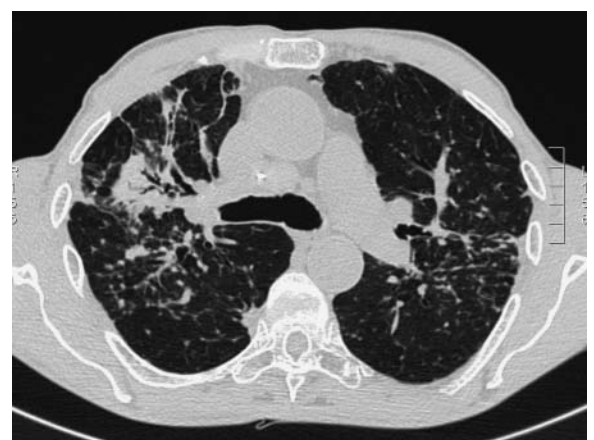
Diseases with a (peri)lymphatic distribution are sarcoidosis, lymphangitic spread of tumour and silicosis and coal miners' pneumoconiosis (Figs. 6.9 and 6.10). Amyloidosis and lymphoproliferative diseases such as lymphoma and lymphocytic interstitial pneumonia can also show (peri)lymphatic nodules but are less common (PASLAWSKI et al. 2003). Diseases with a (peri)lymphatic distribution usually show different patterns of involvement of the (peri)lymphatic interstitium Table 6.5 (AKIRA 2002; AKIRA et al. 2005; ANTAO et al. 2005; AYUSO et al. 1987; BRAUNER et al. 1989; DAWSON and MÜLLER 1990; EISENHUBER 2002; GRAHAM et al. 1992; HONDA et al. 1999; JOHKOH et al. 1992, 1999; KIM et al. 1999; LYNCH et al. 1989; MÜLLER et al. 1989; NISHIMURA et al. 1993; REN et al. 1989; URBAN et al. 1993; UTZ et al. 1996).



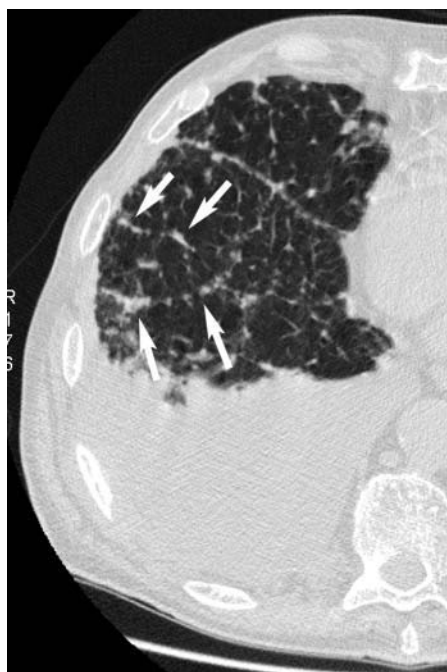
**Fig. 6.7.** A nodular pattern with (peri)lymphatic distribution typically shows peribronchovascular nodules, subpleural nodules, nodules in the interlobular septa and centrilobular nodules



**Fig. 6.8.** (Peri)lymphatic distribution of nodules in a patient with sarcoidosis. Nodules are predominantly seen in the axial peribronchovascular connective tissue and in the subpleural connective tissue. The latter are best visualised when close to the fissure (*arrows*). Note that the conglomeration of the peribronchovascular nodules has resulted in the development of a large and irregular axial mass



**Fig. 6.9.** (a) In early coal workers' pneumoconiosis the (peri)lymphatic nodules are predominantly located in the subpleural and centrilobular connective tissue of the upper lung areas. (b) In more advanced disease, peribronchovascular nodules are also seen together with fibrotic masses



**Fig. 6.10.** In lymphangitic spread of tumour, the presence of (peri)lymphatic nodules is often associated with linear opacities also caused by the lymphatic spread of tumour, creating a beaded septum appearance (*arrows*)

**Table 6.5.** Differential diagnosis of nodules with a (peri)lymphatic distribution

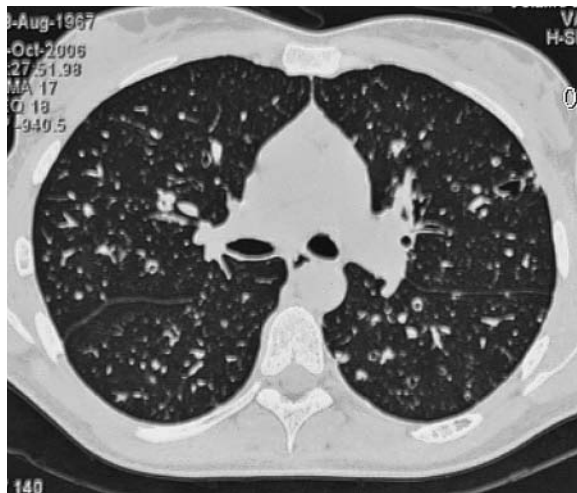
	Appearance	Distribution	Remarks and associated findings
Sarcoidosis	Several mm to 1 cm Masses (1–4 cm) Well defined	Perihilar, peribronchovascular Subpleural Centrilobular Septal Upper lobes, asymmetric	Nodules may be ill-defined
Silicosis and coal workers' pneumoconiosis	2–5 mm Masses up to several cm Well defined	Subpleural Centrilobular Upper lobes, bilateral, right sided predominance	Fibrotic changes surrounding nodules causing emphysema
Lymphangitic spread of tumour	Several mm Well defined	Peribronchovascular Subpleural Centrilobular Septal Uni- or bilateral Patchy May be asymmetric	Often associated with linear opacities creating "beaded septum" appearance
Diffuse amyloidosis	Small nodules Well defined	Subpleural Peribronchovascular Septal Lower lung	Diffuse, linear interstitial pattern is more common Large nodules (nodular parenchymal amyloidosis) and consolidation can be present Nodules may calcify
Lymphoproliferative disease (lymphoma, lymphocytic interstitial pneumonia [LIP])	Small nodules Well defined	Subpleural Centrilobular Peribronchovascular Septal	LIP is usually associated with dysproteinemia, autoimmune disease (Sjögren) or AIDS Lymphoma: multiple small nodules is rare presentation, solitary nodule or poorly defined opacity (2–3cm) is more frequent



### 6.3.2

#### Centrilobular Distribution

The central part of the secondary pulmonary lobule contains the branches of the terminal bronchioles, their accompanying pulmonary arteries and adjacent to them supporting connective tissue and lymph vessels. Hence, centrilobular nodular opacities can result from bronchiolar and peribronchiolar diseases and from vascular and perivascular diseases that predominantly involve the proximal (centrilobular) branches, from (peri)lymphatic diseases and diseases involving the centrilobular peribronchovascular interstitium. As mentioned earlier, diseases with a typical interstitial thickening usually present as lines. That is why involvement of the centrilobular peribronchovascular interstitium usually results from extension of bronchiolar and peribronchiolar diseases (Fig. 6.11) as well as vascular and perivascular diseases in this interstitium. Centrilobular nodular opacities are also seen in lymphatic and (peri)lymphatic diseases (see Sect. 6.3.1) but then in most cases nodular opacities are seen in the other lung compartments that contain lymphatic vessels (interlobular septa, subpleural space and axial peribronchovascular connective tissue) too. Hence when nodules are seen



**Fig. 6.11.** Langerhans histiocytosis presenting with multiple centrilobular interstitial nodules located in the wall of the small airways. Note also the cystic changes. The combination of centrilobular nodules and cystic lesions is suggestive for Langerhans histiocytosis



**Fig. 6.12a,b.** Invasive aspergillosis in an immunosuppressed patient. Multiple airspace nodules of different sizes and shapes. In the angioinvasive form, these nodules are typically surrounded by a halo of ground-glass (arrows), an expression of perilesional haemorrhage: the halo sign. These opacities may cavitate and an inclusion may become visible, separated from the wall of the cavity by a hyperlucent meniscus: the air crescent sign (arrowhead)

that are separated from the pleural surfaces and the interlobular septa by a distance of 5–10 mm with no nodules in the subpleural spaces or other compartments where lymph vessels are located, a centrilobular distribution of the nodular pattern caused by either bronchiolar/peribronchiolar disease (Figs. 6.2, 6.3, 6.12, 6.13) or (centrilobular) vascular/perivascular disease (Fig. 6.6) can be concluded (Fig. 6.14). Table 6.6 shows the diseases that can present with centrilobular nodular opacities (AKIRA et al. 1999; BRAUN et al. 1979; FRANQUET et al 2002; GALLARDO et al 2006; IM et al. 1993; ITOH et al. 1978; KOKKARINEN et al. 1994; MOHR 2004; NAIDICH et al. 1985).

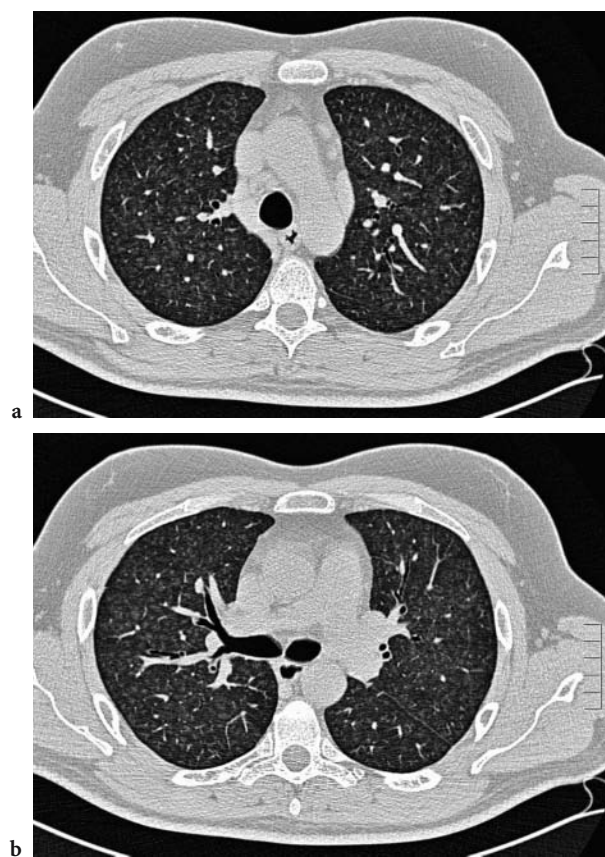


Fig. 6.13a,b. Hypersensitivity pneumonitis. Multiple centrilobular ill-defined airspace nodules in both lungs

Table 6.6. Differential diagnosis of centrilobular nodules

Bronchiolar and peribronchiolar diseases	
●	Infectious bronchiolitis (viral, mycoplasma, aspergillus, bacterial, tuberculosis) and bronchopneumonia
●	Aspiration
●	Cystic fibrosis
●	Allergic bronchopulmonary aspergillosis
●	Hypersensitivity pneumonitis
●	Organising pneumonia
●	Bronchioloalveolar carcinoma
●	Follicular bronchiolitis (rheumatoid arthritis [RA], Sjögren disease, AIDS)
●	Panbronchiolitis
●	Smoking-associated bronchiolar disease (respiratory bronchiolitis [RB], respiratory bronchiolitis interstitial lung disease [RB-ILD])
●	Early asbestosis
●	Langerhans cell histiocytosis
Vascular and perivascular diseases	
●	Tumour thrombotic microangiopathy
●	Vasculitis (Wegener's granulomatosis, Churg-Strauss syndrome)
●	Pulmonary haemorrhage
●	Metastatic calcification
●	Fat embolism

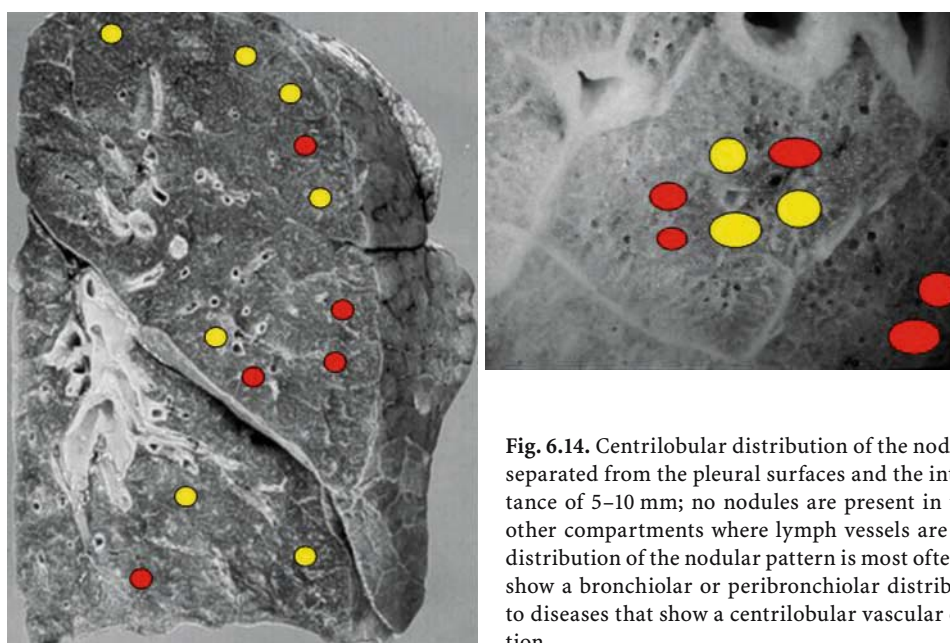


Fig. 6.14. Centrilobular distribution of the nodular pattern: nodules are separated from the pleural surfaces and the interlobular septa by a distance of 5–10 mm; no nodules are present in the subpleural spaces or other compartments where lymph vessels are located. A centrilobular distribution of the nodular pattern is most often caused by diseases that show a bronchiolar or peribronchiolar distribution but can be related to diseases that show a centrilobular vascular or perivascular distribution

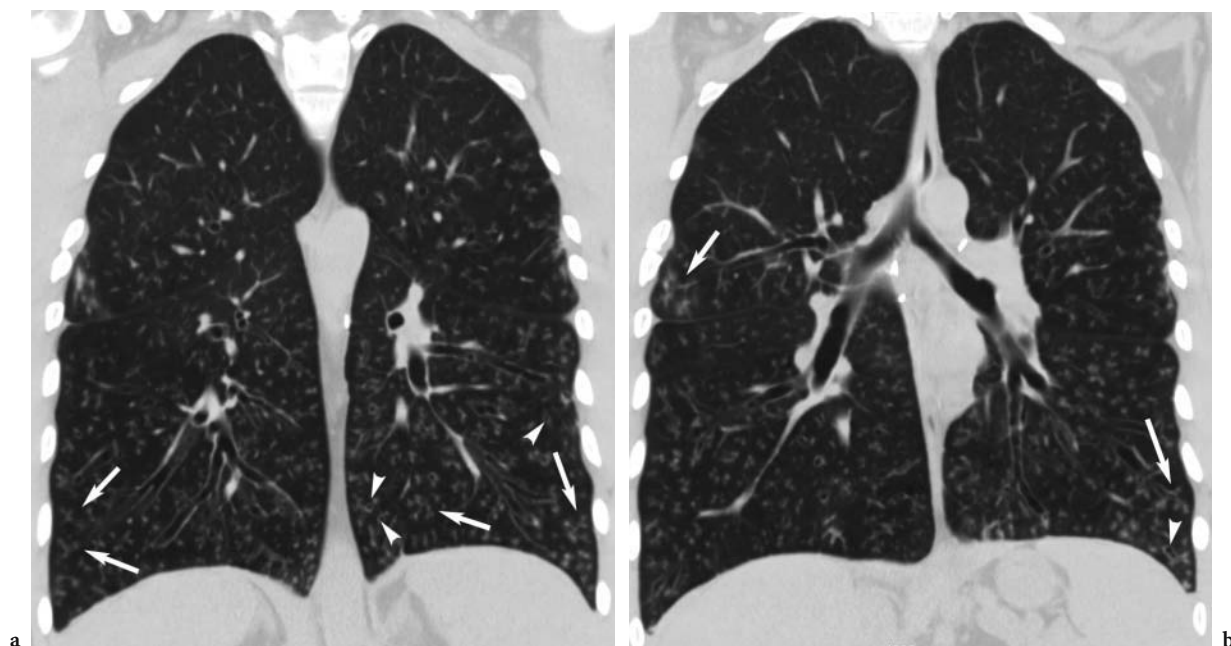
### 6.3.3

#### Centrilobular Distribution with a Tree-in-Bud Pattern

Centrilobular nodular opacities can be associated with the presence of intralobular branching lines creating the tree-in-bud pattern (AQUINO et al. 1996; COLLINS et al. 1998; GRUDEN et al. 1994; GRUDEN and WEBB 1995; IM et al. 1993). In most instances, this pattern reflects the presence of dilated centrilobular bronchioles, with their lumina impacted with mucus, fluid or pus, and peribronchiolar inflammation but can also be seen in diseases with predominantly cellular filling of the bronchiolar lumen and disease with predominantly peribronchiolar changes (Fig. 6.15). The presentation of the tree-in-bud depends on the relationship of the bronchioles to the plane of the scan. Sometimes the intralobular branching lines are the most striking finding (see Sect. 7.2.2.2 in Chap. 7), sometimes the centrilobular cluster of nodules is the dominant finding, while the impacted bronchiole may also appear as a single centrilobular nodule with a diameter of a few millimetres. Intralobular branching lines are predominantly seen in the lung periphery, whereas single

nodules are often seen in the costophrenic angles. While the nodules of the tree-in-bud pattern are often sharply defined, associated ill-defined centrilobular nodular opacities are often present as well and represent inflammatory changes in the surrounding airspaces. In addition, bronchiolar dilatation, large airway thickening and even bronchiectasis – which are signs of airway involvement – are often present (GRUDEN et al. 1994) (Fig. 6.15).

The presence of tree-in-bud is indicative of small airway disease and is in the majority of cases associated with airway infection, explaining why the (proximal) large airways are also often involved, and why the (distal) airspaces are often also opacified. However, tree-in-bud may also be seen in absence of infection (HOWLING et al. 1999). Sarcoidosis and lymphangitic spread of tumour (Fig. 7.12) typically showing centrilobular (peri)lymphatic nodules may sometimes also show the tree-in-bud pattern. Table 6.7 lists the diseases that can show the tree-in-bud pattern (AKIRA et al. 1988; AQUINO et al. 1996; COLLINS et al. 1998; GRUDEN et al. 1994; HOWLING et al. 1999; IM et al. 1993; LYNCH et al. 1990; MÜLLER and MILLER 1995; NISHIMURA et al. 1992).



**Fig. 6.15a,b.** Infectious bronchiolitis with centrilobular changes: branching lines, small nodules, rosettes of nodules and the tree-in-bud pattern (*arrows*). Note also the thickening of the wall of the larger bronchi, indicating bronchitis and wall thickening and dilatation of some bronchioles (*arrowheads*)



**Table 6.7.** Bronchiolar and peribronchiolar diseases that can show the tree-in-bud pattern

Frequent finding
<ul style="list-style-type: none"> <li>● Infectious bronchiolitis (especially bacterial, tuberculosis and nontuberculous mycobacteria) and bronchopneumonia</li> <li>● Aspiration</li> <li>● Cystic fibrosis</li> <li>● Bronchiectasis</li> <li>● Panbronchiolitis</li> </ul>
Less frequent finding
<ul style="list-style-type: none"> <li>● Allergic bronchopulmonary aspergillosis</li> <li>● Bronchioloalveolar carcinoma</li> <li>● Organising pneumonia</li> <li>● Follicular bronchiolitis (rheumatoid arthritis [RA], Sjögren disease, AIDS)</li> </ul>
Mimics (non bronchiolar or peribronchiolar diseases)
<ul style="list-style-type: none"> <li>● Sarcoidosis</li> <li>● Lymphangitic spread of tumour</li> <li>● Tumour thrombotic microangiopathy</li> </ul>

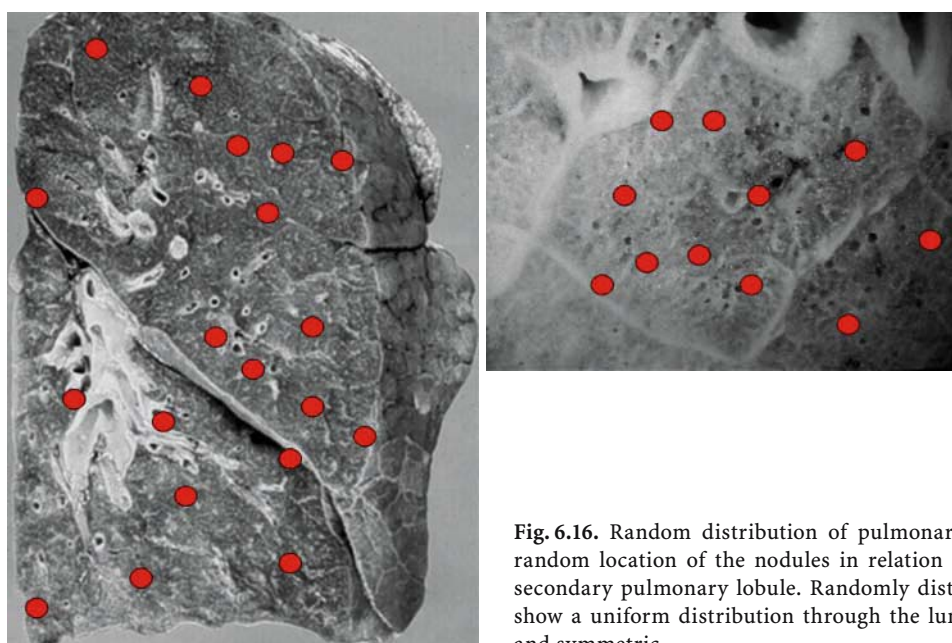
### 6.3.4

#### Random Distribution

Random distribution refers to the random location of the nodules in relation to the structures of the secondary pulmonary lobule. Nodules may be located near the centre of lobule, near the interlobular septa and in the lung parenchyma in between. They can, however, also be seen in relation to the pleural surfaces and the pulmonary arterial branches (the so-called feeding vessels) but have no consistent or predominant relationship with any of these structures or the structures of the secondary pulmonary lobule. In addition, they usually show a uniform distribution through the lung that is often bilateral and symmetric but rarely patchy (Fig. 6.16).

Random distribution of nodules results from a vascular spread of disease in which the pathological agent may pass the centrilobular area and distributes along the small vessels and capillaries of the lobule.

Small nodules that appear randomly distributed are seen in patients with miliary tuberculosis, miliary fungal infections, and haematogenous metastases (HONG et al. 1998; IM et al. 1995; OH et al. 1994; VOLOUDAKI et al. 1999) (Figs. 6.17 and 6.18). These nodules are usually well defined. They are often seen in relation to small vessels in some locations



**Fig. 6.16.** Random distribution of pulmonary nodules refers to the random location of the nodules in relation to the structures of the secondary pulmonary lobule. Randomly distributed nodules usually show a uniform distribution through the lung and is often bilateral and symmetric



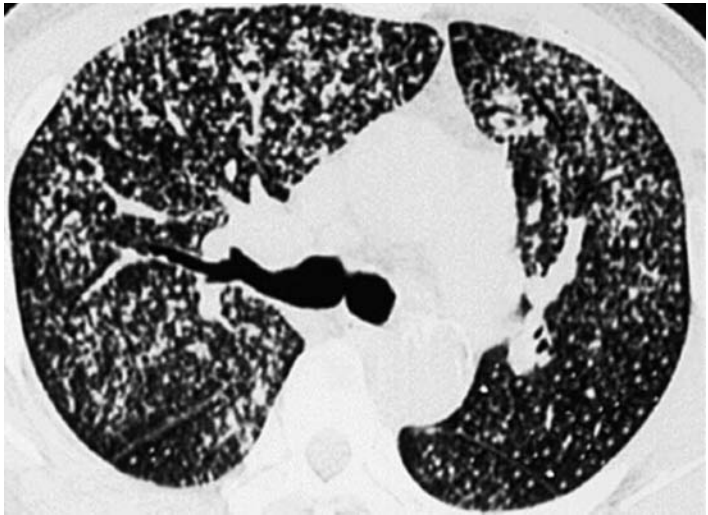


Fig. 6.17. Random distribution of lung nodules in a patient with miliary tuberculosis

Table 6.8. Differential diagnosis of nodules showing a random distribution

- Miliary infection: tuberculosis, fungus
- Miliary metastases: thyroid cancer, renal cancer, melanoma

and have a tendency to predominate in the lung periphery and at the lung bases, very likely reflecting their mode of dissemination (MURATA et al. 1992). Table 6.8 lists the disease that can show randomly distributed nodules (HIRAKATA et al. 1993; MILNE and ZERHOUNI 1987).

However, it should be emphasized that in diseases with a (peri)lymphatic distribution such as sarcoidosis, silicosis and coal miners' pneumoconiosis and in diseases with a centrilobular distribution such as

Langerhans cell histiocytosis, nodules may appear as randomly distributed, particularly when they are numerous and diffuse.

Metastases may be larger and less profuse, showing nodular opacities of different sizes with a basilar dominance and originate from lung, heart or gastrointestinal tract (AKIRA et al. 1999) (Fig. 6.19). A connection between these nodules and the adjacent pulmonary vessels is frequently seen. The metastatic nodules may also be either cavitory or surrounded by a halo of ground-glass attenuation, which is typical of haemorrhagic metastasis (GAETA et al. 1999) (Fig. 6.20). Vascular spread of infection can also cause larger, well-defined peripheral nodules ranging from 5 to 35 mm with feeding vessels or wedge-shaped peripheral lesions with or without necrosis: septic emboli.

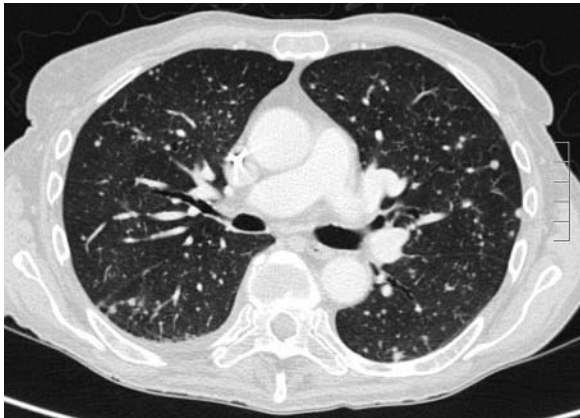


Fig. 6.18. Random distribution of lung nodules in a patient with haematogenous metastases



Fig. 6.19. Metastases may be larger and less profuse, showing nodular opacities of different sizes with a basilar predominance



**Fig. 6.20.** Metastases may be surrounded by a halo of ground-glass opacity, which is typical of haemorrhagic metastases

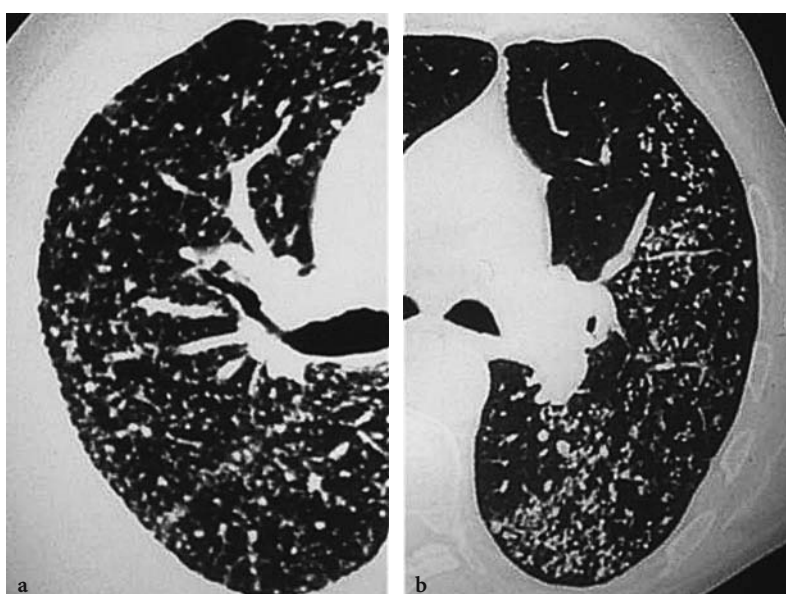
### 6.3.5 Diagnostic Algorithm

Distinguishing between the (peri)lymphatic and random distribution, on one hand, and the centrilobular distribution of nodular opacities, on the other hand, is most easily accomplished by looking first for nodules in the subpleural region. Involvement of the subpleural region is best appreciated at the fissures because nodules are then surrounded by air.

If no subpleural nodules are found, the distribution is very likely centrilobular. In the next step, the tree-in-bud pattern should be sought. If the tree-in-bud pattern is found, the differential diagnosis list of this pattern should be consulted, which shows a number of diseases that involve the airways (Table 6.7). The differential diagnosis of centrilobular nodular opacities not associated with a tree-in-bud pattern is long and includes bronchiolar and peribronchiolar and vascular and perivascular diseases (Table 6.6).

If numerous subpleural and fissural nodules are present, the pattern is either (peri)lymphatic or random. The pattern is (peri)lymphatic if nodules are also found in the peribronchovascular interstitium and the interlobular septa, two areas where lymphatic channels are present. It should be emphasised that, since lymphatics are also found at the core of the secondary pulmonary lobule, centrilobular nod-

**Fig. 6.21a,b.** (Peri)lymphatic (a) vs centrilobular (b) distribution of disease. (a) Patient with sarcoidosis showing numerous subpleural and fissural nodules. Since nodules are also found in other areas where lymphatics are located (peribronchovascular interstitium, interlobular septa and centrilobular) diagnosis of disease with a (peri)lymphatic distribution can be made. (b) Patient with infectious bronchiolitis (tuberculosis) showing centrilobular changes (nodules, branching lines and tree-in-bud), suggesting disease that predominantly involves the airways



ules are often seen as well. Because of the presence of nodules in other areas where lymphatics are found, differential diagnosis with purely centrilobular nodules is usually easy (Fig. 6.21). Table 6.5 lists the diseases where nodules predominantly show a (peri)lymphatic distribution. The pattern is random if the nodules show a random relation to the structures of the secondary pulmonary lobule and when they are distributed in a diffuse and uniform manner. In that case, differential diagnosis is usually limited to miliary spread of tumour or infection (Table 6.8).

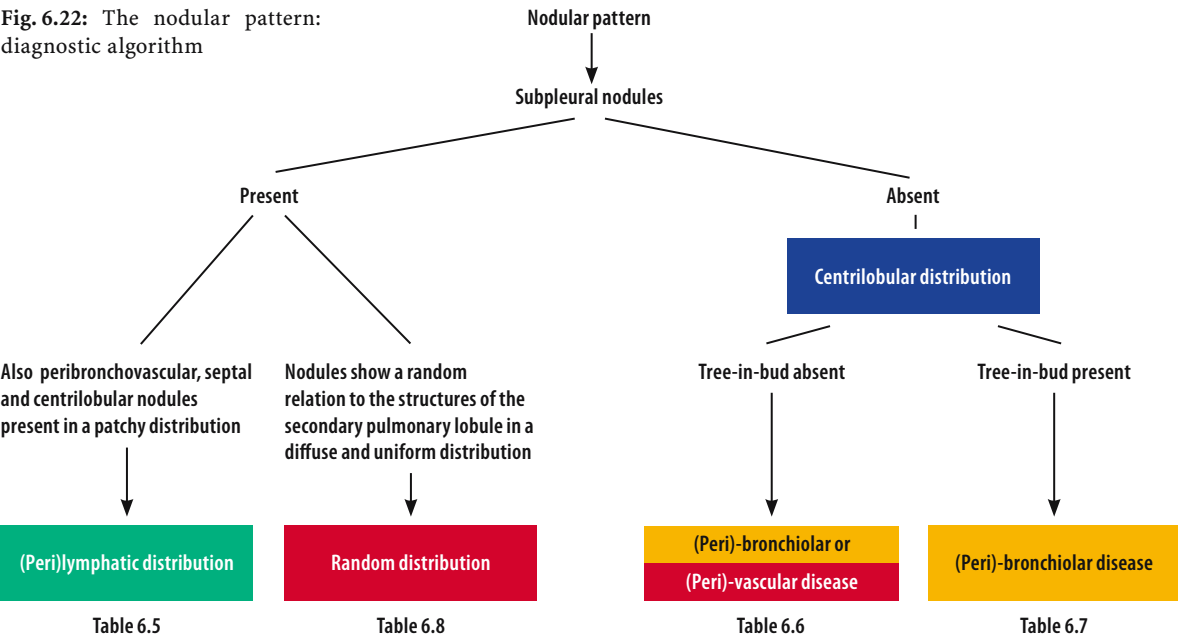
It should be emphasised that subpleural nodules are a frequent finding. In smokers, usually a few subpleural but also centrilobular nodules can be found and are probably related to the presence of fibrosis and accumulated particulate material related to the pathway of lymphatic drainage (REMY-JARDIN et al. 1993a, 1993b). That is why the presence of a few subpleural nodules is aspecific and can be seen regardless of the pattern. A few subpleural nodules that look different (larger, smaller, differently defined) than the other nodules when found among predominantly centrilobular, random or even (peri)lymphatic distributed nodules are unlikely to be related to the patient's disease and should be ignored.

Finally, Table 6.9 shows the regional distribution of the diseases that most frequently cause nodular opacities.

Table 6.9. Regional distribution of nodular lung diseases

Upper lung vs lower lung vs diffuse
<ul style="list-style-type: none"><li>● <b>Upper:</b> Langerhans cell histiocytosis, sarcoidosis, silicosis and coal workers' pneumoconiosis, tuberculosis, respiratory bronchiolitis interstitial lung disease [RB-ILD]</li><li>● <b>Lower:</b> asbestosis, organising pneumonia, haematogenous metastases, alveolar haemorrhage</li><li>● <b>Diffuse:</b> hypersensitivity pneumonitis, diffuse pneumonia, lymphangitic spread of tumour, haematogenous metastases, sarcoidosis</li></ul>
Central lung vs peripheral lung
<ul style="list-style-type: none"><li>● <b>Central:</b> sarcoidosis, silicosis and coal workers' pneumoconiosis, lymphangitic spread of tumour</li><li>● <b>Peripheral:</b> asbestosis, nonspecific interstitial pneumonia [NSIP], organising pneumonia, hypersensitivity pneumonitis, haematogenous metastases, septic emboli, small airways disease</li></ul>
Posterior vs anterior lung
<ul style="list-style-type: none"><li>● <b>Posterior:</b> asbestosis, silicosis and coal workers' pneumoconiosis, sarcoidosis, hypersensitivity pneumonitis</li></ul>
Can be unilateral or asymmetric
<ul style="list-style-type: none"><li>● Pneumonia, lymphangitic spread of tumour, sarcoidosis</li></ul>

Fig. 6.22: The nodular pattern: diagnostic algorithm



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# Linear Pattern

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## 7.1

### Introduction

The linear pattern is characterised by the presence of lines that occur when elongated structures or compartments of the lung that traverse the lung parenchyma parallel to the CT scan plane are involved. The introduction of multidetector CT and its ability to produce high-detail coronal and sagittal reconstructions in addition to the axial slices has improved the recognition of these linear opacities. When these lines cross each other, a netlike appearance can occur, which explains why the pattern is also often called the reticular pattern.

Given its anatomical distribution, it is especially the thickening of the pulmonary interstitium that will result in the appearance of linear and reticular opacities. This interstitial thickening can result from the presence of fluid, from infiltration of the interstitium with cells or with other material, and from fibrous changes. Depending on the cause, the lines may vary from smooth to nodular and irregular.

Thickened connective tissue strands of the peripheral interstitium that penetrate deeply into the

lung between the secondary pulmonary lobules and between the acini, are responsible for the development of respectively septal lines and intralobular lines.

Because part of the interstitium does not cross the lung parenchyma but is located adjacent to the pleura and adjacent to the bronchovascular structures, interstitial thickening will not only present as lines traversing the lung parenchyma. Thickening of the subpleural part of the peripheral interstitium (subpleural interstitial thickening) will be perceived as pleural thickening or thickening of the fissures. Thickening of the axial interstitium surrounding the large bronchovascular structures (peribronchovascular interstitial thickening) is usually perceived as an increase in bronchial wall thickness or an increase in diameter of the pulmonary arteries. In addition, thickening of the axial interstitium surrounding the peripheral small bronchovascular branches can present as centrilobular branching lines extending from the centre to the periphery of the secondary pulmonary lobule.

In many interstitial lung diseases interstitial fibrosis may develop. When this occurs the interstitial thickening usually becomes irregular in appearance, which is reflected in an irregular subpleural and peribronchovascular thickening and in irregular septal and intralobular lines. Thickening of the interstitium may also have nodular elements which may be due to focal cellular infiltration or to focal fibrosis.

It should be emphasised that thickening of the parenchymal interstitium that surrounds the alveoli does not cause linear opacities because the changes are too small to be seen directly with CT. However, a small increase in lung density (ground-glass pattern) can often be appreciated.

An important part of the pulmonary interstitium is interlaced with lymphatics. Therefore, thickening of the lymphatics or the perilymphatic tissues can cause linear opacities similar to those seen when the interstitium is thickened, although, as will be dis-

cussed further on, the location of these lines within the secondary pulmonary lobule is somewhat different compared to the purely interstitial lines. This is related to the distribution of the lymphatic channels in the secondary pulmonary lobules.

Airways and blood vessels are also branching structures and pathology in the lumen and/or the wall of these airways and blood vessels can result in the appearance of linear opacities. While pathology of the large airways and blood vessels is predominantly appreciated as an increase in thickness of the bronchial wall or as an increase in diameter of the pulmonary arteries, pathology in and around the small distal bronchioles and arterioles can again cause centrilobular branching lines. It should be emphasised that the difference in location between arteries and veins is important. Because of their location in the interlobular septa, pathology related to the veins predominantly presents as septal lines.

When linear opacities that cross the lung parenchyma are thick and long and when they cannot be identified as septal or intralobular lines, the term “parenchymal band” is used to describe them. A parenchymal band refers to a linear or reticular opacity usually several millimetres in thickness and from 2–5 cm in length. The presence of these parenchymal bands usually indicates atelectasis or advanced pulmonary fibrosis, although they can represent contiguous thickened interlobular septa. In the latter situation, it is better, however, not to use the term “parenchymal band” but to describe the abnormalities as septal lines or septal thickening because they have a different differential diagnosis. When caused by interstitial fibrosis, these parenchymal bands are usually accompanied by lung destruction and lung distortion.

In the next part of this chapter, these different types of linear opacities will be described and discussed in more detail.

## 7.2

### Types of Linear Opacities

#### 7.2.1

##### Septal Lines

Septal lines (SLs) occur when the interlobular septa are thickened. They are usually 1–2 cm in length and outline a part or the entire secondary pulmonary

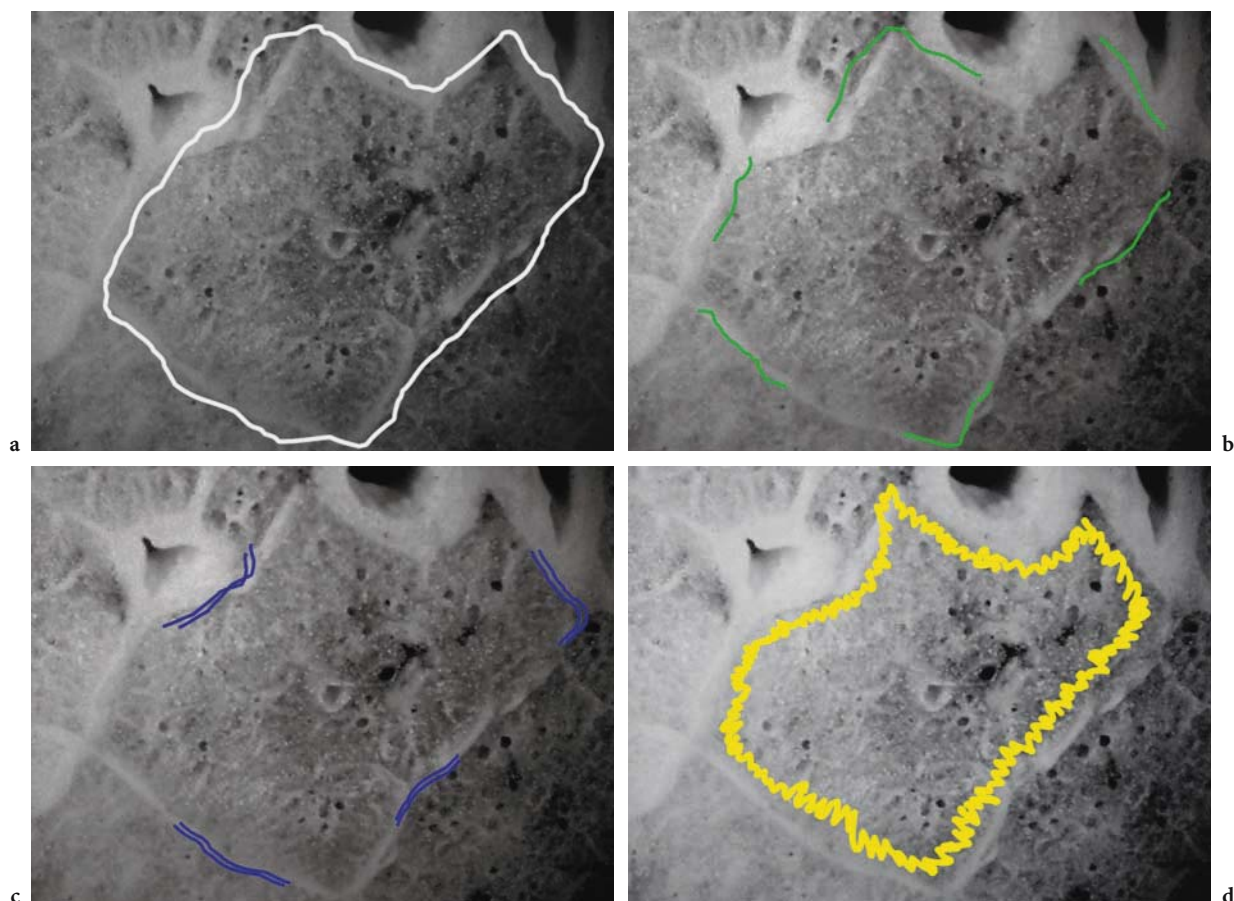
lobule. They usually extend to the pleural surface and are roughly perpendicular to the pleura (WEBB 1989; ZERHOUNI 1989; MUNK et al. 1988; STEIN et al. 1987; ABERLE et al. 1988; SWENSEN et al. 1989; MÜLLER et al. 1986; MURATA et al. 1986) (Fig. 7.1). Secondary pulmonary lobules at the periphery of the lung may have a variety of appearances, but they are often longer than wide, while lobules within the central lung appear more polygonal or sometimes hexagonal in shape.

Septal thickening can be smooth, nodular or irregular in contour (KANG et al. 1996), depending on the pathological process that causes the thickening.

Knowledge of the anatomy of the interlobular septum helps to understand which pathological changes can be responsible for this septal thickening. Since the interlobular septa are predominantly made up of connective tissue from the peripheral interstitium, thickening is commonly seen in patients with interstitial lung disease (Figs 7.1a, 7.2). However, also lymphatics traverse the interlobular septa, explaining why pathological changes in and around the lymphatics can also be responsible for the development of septal lines (Figs. 7.1b, 7.3). The presence of veins explains why venous congestion can also manifest with thickening of the interlobular septa (Figs. 7.1c, 7.4).

However, it has been shown that airspace filling can also present as linear opacities. This linear appearance can mimic septal lines and is caused by linear deposition of material within the airspaces at the borders of the secondary pulmonary lobules (JOHKO et al. 1999a, 1999c) (Figs. 7.5, 7.1d). This pulmonary involvement occurring predominantly in relation to the interlobular septa and the periphery of the lobules has been termed perilobular (MURATA et al. 1989; JOHKO et al. 1999c; UJITA et al. 2004) or the perilobular pattern. This phenomenon can be the only cause of the development of septal lines, but can probably also be present together with real septal line thickening in those diseases that affect both the interstitium and the airspaces. CT is not able to differentiate between these two causes.

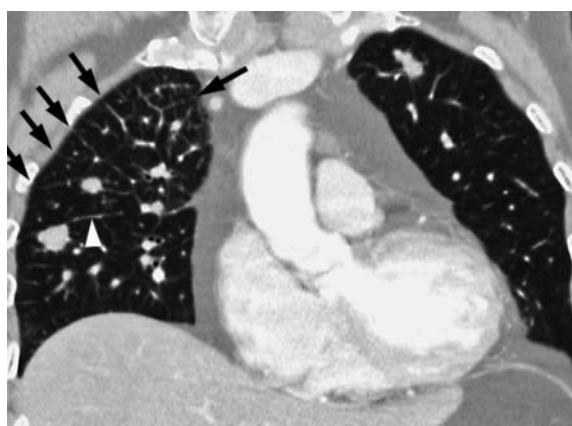
Smooth septal thickening is often seen in association with ground-glass opacity, creating a pattern termed crazy-paving (Fig. 7.6). The ground-glass opacity can then be caused by thickening of the parenchymatous interstitium that is too small to become visible as individual lines, by limited filling of the airspaces or by a combination of both.



**Fig. 7.1a-d.** Septal lines can be caused: **a** by thickening of the interlobular interstitium, **b** by diseases in and around the lymphatics, **c** in case of venous congestion, **d** can be stimulated by linear deposition of material within the airspaces at the borders of the secondary pulmonary lobules

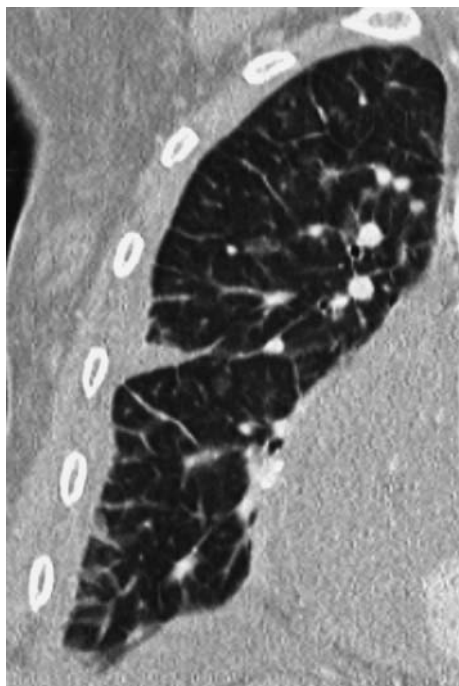


**Fig. 7.2.** Septal lines caused by thickening of the interstitium in a patient with interstitial amyloidosis



**Fig. 7.3.** Septal lines caused by lymphangitic tumour spread. Multiple septal lines can be seen in the right lung delineating the secondary pulmonary lobules (arrows). Note also the pulmonary metastases and the thickening of the minor fissure (arrowhead)





**Fig. 7.4.** Septal lines caused by venous congestion. Note also pleural fluid extending into the minor fissure



**Fig. 7.5.** Peribulbar pattern caused by organising pneumonia. A peribulbar pattern is seen in the anterior part of the right upper lobe and presents as septal lines (arrows). Note also the areas of lung consolidation and ground-glass opacity in the posterior part of the lower lobe

Table 7.1 describes the diseases often associated with the presence of septal lines and indicates which of these may be associated with ground-glass opacity creating the crazy-paving pattern.

**Table 7.1.** Most important causes of septal lines in relation to the anatomy of the secondary pulmonary lobule with mention of whether these lines are usually smooth or nodular

### 1. Lymphatics

- Lymphangitic tumour spread: usually smooth, sometimes nodular (C)
- Lymphoproliferative disease: lymphoma, lymphocytic interstitial pneumonia (LIP): smooth or nodular
- Sarcoidosis: usually nodular or irregular (C)
- Increased lymphatic flow: smooth (GG)
- Silicosis and coal workers' pneumoconiosis: usually nodular when active, irregular in endstage disease

### 2. Interstitium (thickening connective tissue) and/or linear deposition of material within the airspaces at the borders of the lobuli (perilobular)

- Interstitial lung disease
  - Idiopathic pulmonary fibrosis (IPF) or other causes of usual interstitial pneumonia (UIP): usually irregular
  - Nonspecific interstitial pneumonia (NSIP) smooth or irregular (GG)
  - Acute interstitial pneumonia (AIP): smooth (GG)
- Asbestosis: irregular
- Amyloidosis: smooth or irregular
- Pneumonia (viral, pneumocystis jiroveci pneumonia) (GG)
- Alveolar haemorrhage (C, GG)
- Bacterial pneumonia (GG)
- ARDS (C, GG)
- Organising pneumonia (GG)
- Alveolar proteinosis (C, GG)

### 3. Veins

- Hydrostatic pulmonary oedema: smooth (C, GG)
- Central venous pulmonary obstruction: smooth (GG)

C, common finding in this disease;  
GG, often associated with ground-glass opacity creating the crazy-paving pattern

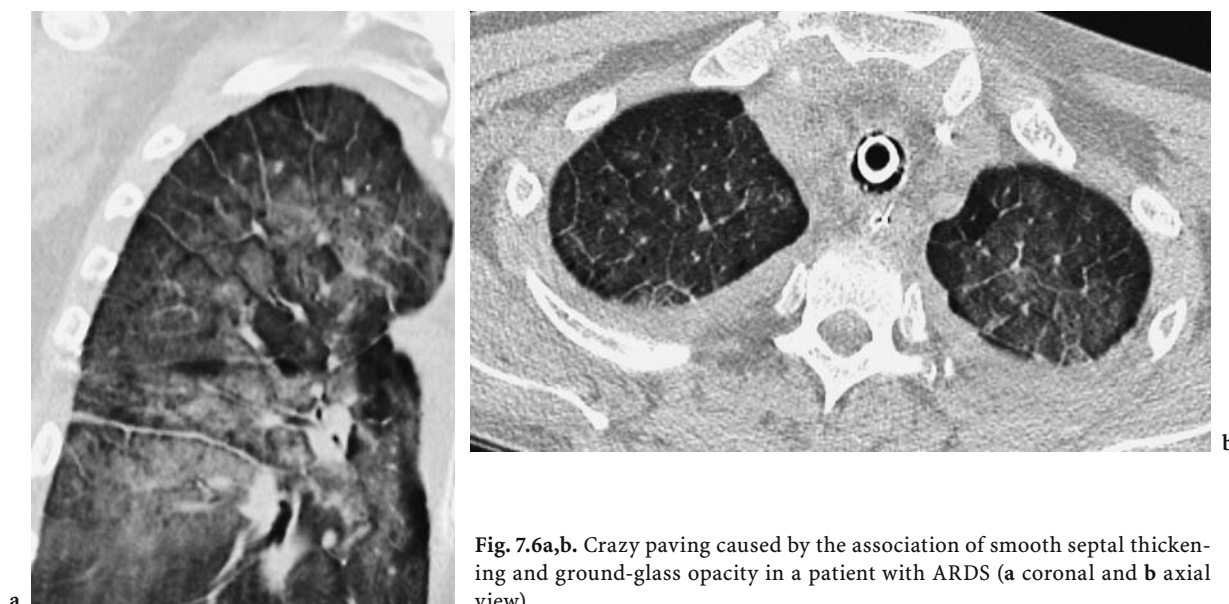


Fig. 7.6a,b. Crazy paving caused by the association of smooth septal thickening and ground-glass opacity in a patient with ARDS (a coronal and b axial view)

- The development of septal lines can be related to:
  - The presence of interstitial lung disease.
  - Disease in and around the lymphatics.
  - Venous congestion.
  - Airspace disease predominantly located in the periphery of the secondary pulmonary lobule (perilobular location).
- Smooth septal thickening is often seen in association with ground-glass opacity, creating the crazy paving pattern.
- Irregular septal thickening may indicate the development of fibrosis.

## 7.2.2

### Intralobular Lines

Intralobular lines are lines located within the borders of the secondary pulmonary lobule. They can either present as a fine and regular intralobular reticular pattern (Fig. 7.7a,b) or as branching lines that extend like spider legs from the center to the periphery of the secondary pulmonary lobule: centrilobular branching lines (Fig. 7.7c–f).

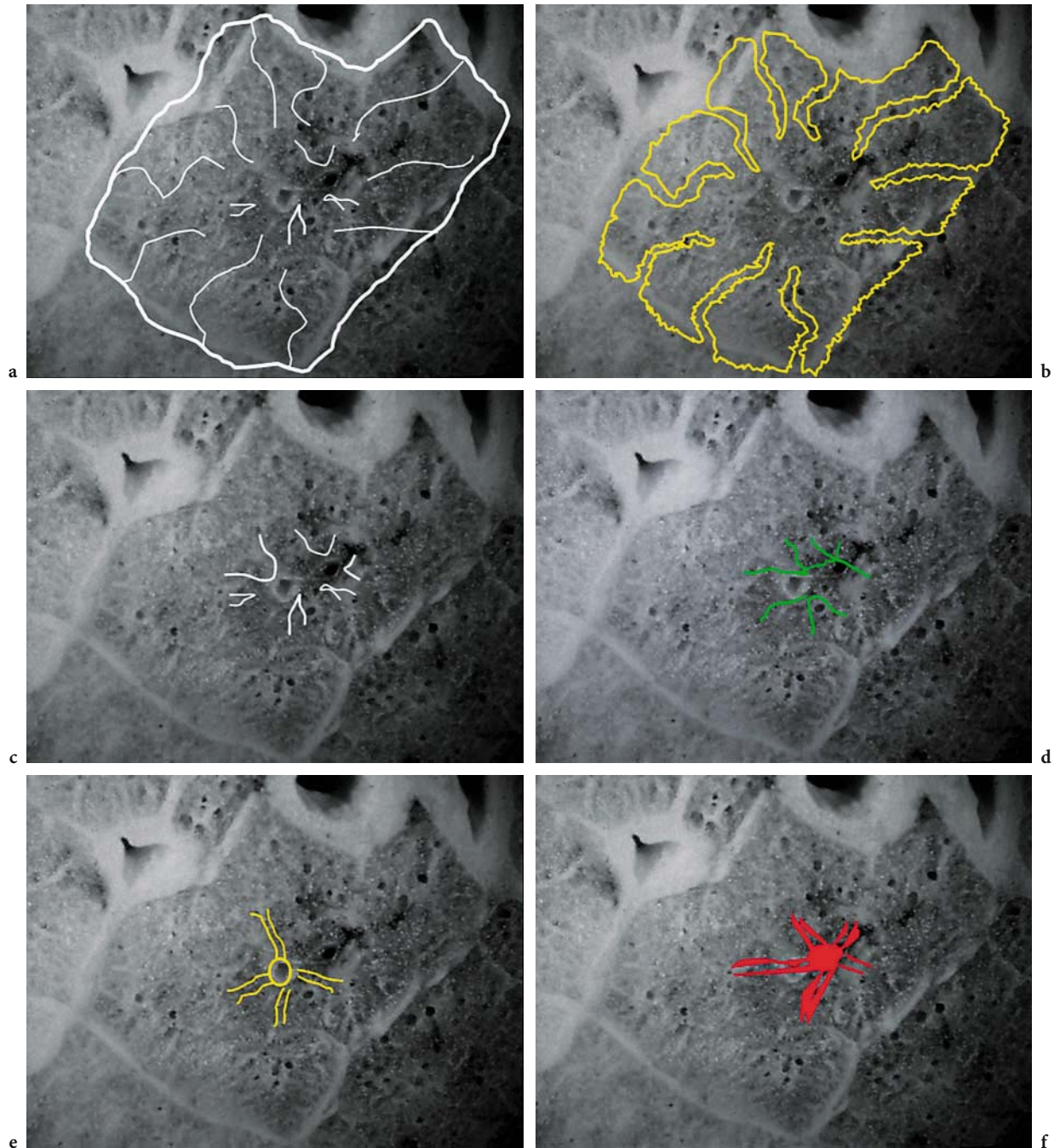
#### 7.2.2.1

##### Intralobular Reticular Pattern

In intralobular reticular pattern (IRP), fine crossing lines of opacity that are separated by a few millimetres are seen. The lung regions showing this pattern have a lace or netlike appearance (WEBB et al. 1988; AUSTIN et al. 1996; ZERHOUNI et al. 1985) (Figs. 7.7a, 7.8).

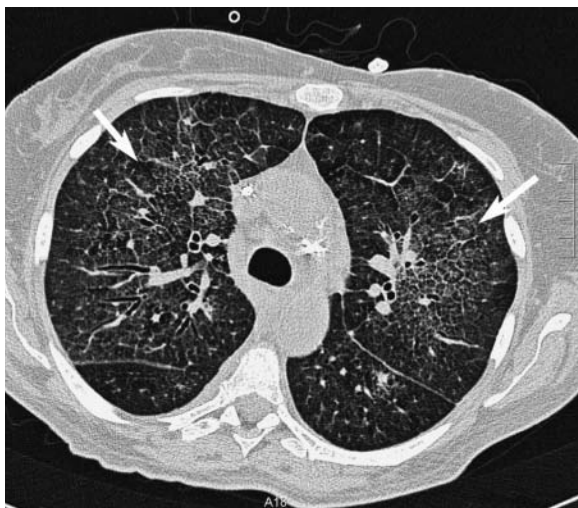
This pattern is most typically seen when the intralobular connective tissue septa are thickened (Fig. 7.8). This thickening can be the result of diffuse interstitial infiltration, interstitial fibrosis or a combination of both changes. When fibrosis is present, very small honeycomb cysts measuring approximately 1 mm in diameter can become visible (NISHIMURA et al. 1992; COLBY and SWENSEN 1996) (Fig. 7.9), corresponding to areas of lung destruction between the thickened and fibrotic septa. The honeycombing pattern is described in detail in Sect. 7.2.6. Since the intralobular septa are in continuity with the interlobular septa and with the subpleural space, septal lines and subpleural interstitial thickening are also often seen. Thickening of the parenchymatous connective tissue will not present as lines because the changes are beyond the resolution of CT but can present as ground-glass opacity.

Another reason why an intralobular reticular pattern may develop is when there is a linear deposition of material within the airspaces at the borders of the acini (JOHNSON et al. 1999a, 1999c) (Fig. 7.7b). Similar

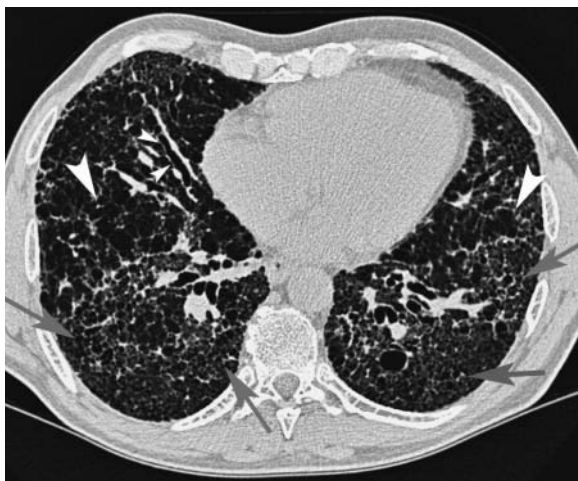


**Fig. 7.7a-f.** The intralobular reticular pattern is seen when the intralobular connective tissue septa are thickened (a) and when there is linear deposition of material within the airspaces at the borders of the acini (b). Centrilobular branching lines are seen when the distal intralobular peribronchovascular interstitium is thickened (c), in case of pathological changes in and around the lymphatics (d), when the centrilobular small airways are involved (e) and when the centrilobular arteries are dilated (f). Note that in (a) also the septal lines are shown





**Fig. 7.8.** Intralobular reticular pattern in a patient with viral pneumonia. A fine pattern of crossing lines of opacity separated by a few millimetres is seen in both upper lobes creating a lace or netlike appearance (*arrows*). Note that when compared with the septal lines in Figs. 7.2–7.4, the distance between the crossing lines is much smaller



**Fig. 7.9.** Irregular intralobular reticular pattern caused by interstitial infiltration and interstitial fibrosis in a patient with idiopathic pulmonary fibrosis. In some areas (*arrows*), multiple very small honeycomb cysts are seen corresponding with areas of lung destruction between the thickened and fibrotic intralobular septa. In other areas (*arrowheads*), the cystic spaces are larger and vary in size from several millimetres to almost 1 cm, indicating more advanced lung destruction. Note also the lung destruction and the traction bronchiectasis (*small arrowheads*). Since these intralobular septa are in continuity with the interlobular septal, some of these irregular lines are septal lines

to the secondary pulmonary lobules, acini are also units of lung structure; accumulation of material in the periphery of these units can be responsible for the development of such a reticular pattern (JONKOH et al. 1999a) (Fig. 7.10).

As in septal thickening, the intralobular reticular pattern may be seen in association with ground-glass opacity, creating again the crazy-paving pattern. The ground-glass opacity is then caused by thickening of the parenchymatous interstitium that is too small to become visible as individual lines, by limited filling of the airspaces or by a combination of both (Fig. 7.10).



**Fig. 7.10.** Crazy paving caused by the association of an intralobular reticular pattern and ground-glass opacity in a patient with pulmonary haemorrhage



- The development of the intralobular reticular pattern is predominantly related to:
  - Interstitial lung disease
  - Airspace disease predominantly located in the periphery of the acini
- The intralobular reticular pattern may be seen in association with ground-glass opacity creating the crazy-paving pattern.
- When fibrosis is present, very small honeycomb cysts measuring about 1 mm in diameter can become visible.



### 7.2.2.2

#### Centrilobular Branching Lines

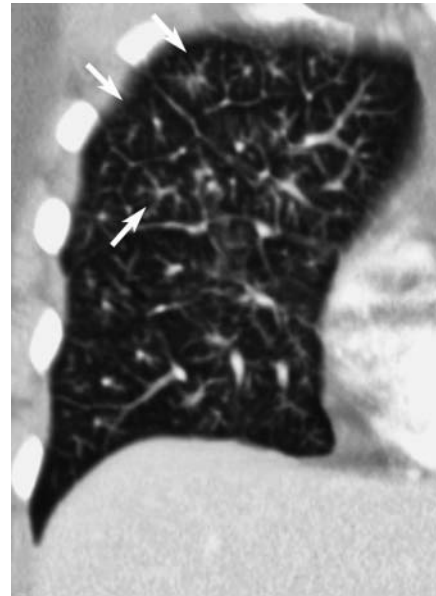
Centrilobular branching lines (CBLs) are Y-shaped or X-shaped opacities at the centre of the secondary pulmonary lobule.

Centrilobular branching lines can be seen when the distal intralobular peribronchovascular interstitium is thickened (WEBB 1989; ZERHOUNI et al. 1985; STEIN et al. 1987; ABERLE et al. 1988) (Figs. 7.7c, 7.11). When this distal part of the axial interstitium is involved, the proximal peribronchovascular interstitium that surrounds the larger bronchovascular structures is also often abnormal. This thickening of the peribronchovascular interstitium can again result from diffuse interstitial infiltration, interstitial fibrosis or a combination of both changes. When fibrosis is present, intralobular bronchioles may become visible. This results from a combination of their dilatation (traction bronchiolectasis) and thickening of the interstitium that surrounds them.

Since lymphatic channels are found in the axial centrilobular connective tissue around bronchioles and arteries, pathological changes in and around the lymphatics can also cause centrilobular branching lines (Figs. 7.7d, 7.12). However, and this is in



**Fig. 7.11.** Centrilobular branching lines in a patient with interstitial amyloidosis. In the anterior lung area, several secondary pulmonary lobules (*black arrows*) can be recognised with Y-shaped opacities in their centre. In the central part of the lung, an intralobular reticular pattern can also be observed (*white arrows*)



**Fig. 7.12.** Centrilobular branching lines in a patient with lymphangitic tumour spread. Besides the smooth to nodular thickening of the interlobular septa in some secondary pulmonary lobules (*arrows*), centrilobular branching lines can also be seen

contrast to the centrilobular branching lines caused by thickening of the peribronchovascular interstitium, these lines are usually not associated with an intralobular reticular pattern (thickening of the intralobular interstitium) because no lymphatic channels are present distal to the respiratory bronchioles (MUNK et al. 1988). On the other hand, because of the dense lymphatic plexus in the interlobular septa, septal lines are almost always present and are often the most striking finding. Ground-glass opacity is less frequently seen and when present it is probably caused by lymph fluid accumulating in the interstitium.

The anatomical organisation of the airways in the secondary pulmonary lobule explains why dilated centrilobular bronchioles with a lumen that is impacted with mucus, pus, fluid or cells can also present as centrilobular branching lines (Figs. 7.7e, 7.13). Indeed, the lobular bronchioles enter the core of the secondary pulmonary lobule and divide from the centre towards the periphery of this lobule into a number of terminal bronchioles according to the size of the lobule (GRUDEN and WEBB 1995; REID and SIMON 1958). Since the arterioles accompany the airways, their pattern of division is similar; also arterioles spread out from the centre to the periphery



**Fig. 7.13.** Centrilobular branching lines (arrows) in a patient with organising pneumonia. Impaction of the centrilobular bronchioles with granulation tissue is responsible for the linear opacities

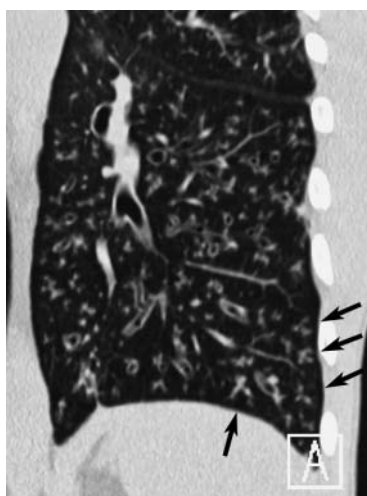
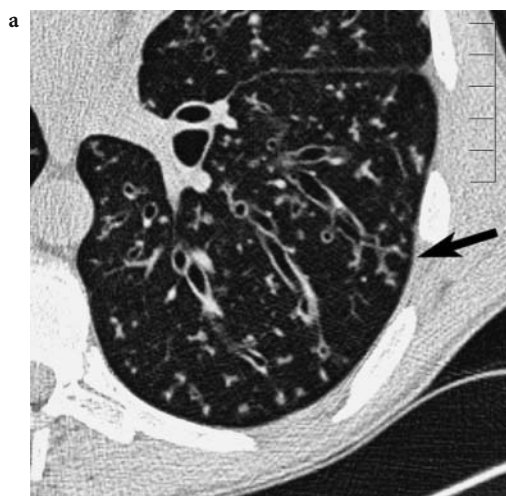


**Fig. 7.14.** Centrilobular branching lines caused by tumour thrombotic microangiopathy (arrows)

of the secondary pulmonary lobule (ELLIOTT and REID 1965) and dilatation of these vessels may also present as centrilobular branching lines (Figs. 7.7f, 7.14) (FRANQUET et al 2002).

It should be emphasised that when these small centrilobular branching lines are cut across by the CT, plane nodular opacities will appear. So in most cases, centrilobular branching lines will be accompanied by the presence of centrilobular nodular opacities; often these nodules are the most striking finding. This appearance has been termed “tree-in-bud” because it resembles a budding or fruiting tree (IM et al. 1993; AKIRA 1988) (Fig. 7.15). This association is seen particularly in bronchiolar disease and was discussed in more detail in chapter 6 section 6.3.3.

- The development of centrilobular branching lines is predominantly related to:
  - Thickening of the distal peribronchovascular interstitium
  - Disease in and around the centrilobular lymphatics
  - Disease affecting the centrilobular bronchioles and arterioles
- Centrilobular branching lines caused by bronchiolar disease are mostly associated with the presence of centrilobular nodules creating the tree-in-bud pattern.
- When fibrosis is present, intralobular bronchioles can become visible (bronchiolectasis).



**Fig. 7.15a,b.** Centrilobular branching lines in a patient with bronchitis and bronchiolitis (arrows). Because centrilobular lines are cut across by the CT plane nodular opacities also appear. The appearance of centrilobular lines together with nodular opacities has been termed tree in bud and usually suggests bronchiolar disease

Table 7.2 describes the diseases that are often associated with the presence of intralobular lines.

Table 7.2. Most important causes of intralobular lines

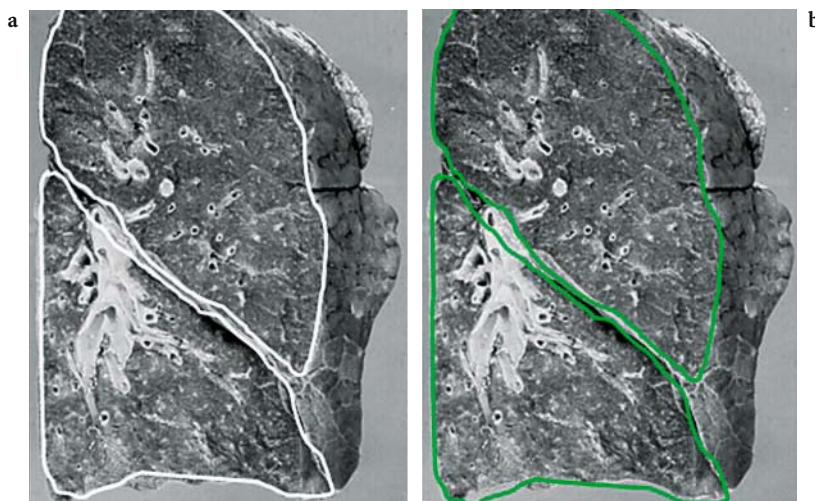
<p><b>1. Intralobular reticular pattern (IRP)</b></p> <p><i>Interstitium (thickening connective tissue) and /or linear deposition of material within the airspaces at the borders of the acini (C, GG)</i></p> <ul style="list-style-type: none"> <li>● Interstitial lung disease (idiopathic or disease-associated) <ul style="list-style-type: none"> <li>● IPF (Idiopathic Pulmonary Fibrosis) or other causes of UIP(C, GG)</li> <li>● Nonspecific Interstitial Pneumonia (NSIP) (C, GG)</li> <li>● Acute interstitial pneumonia (AIP), (C, GG)</li> </ul> </li> <li>● Hypersensitivity pneumonitis (chronic)</li> <li>● Asbestosis (fibrosis)</li> <li>● Amyloidosis</li> <li>● Adult (acute) respiratory distress syndrome ARDS (C, GG)</li> <li>● Radiation pneumonitis (C, GG)</li> <li>● Pulmonary oedema (C, GG)</li> <li>● Alveolar proteinosis (C, GG)</li> <li>● Organising pneumonia</li> <li>● Pulmonary haemorrhage (C, GG)</li> <li>● Pneumonia (viral, pneumocystis jiroveci pneumonia, bacterial) (C, GG)</li> </ul>	<p><i>Disease in and around the centrilobular lymphatics</i></p> <ul style="list-style-type: none"> <li>● Lymphangitic tumour spread: usually smooth, sometimes nodular (C)</li> <li>● Lymphoproliferative disease: lymphoma, lymphocytic interstitial pneumonia (LIP): smooth or nodular</li> <li>● Sarcoidosis: usually nodular or irregular (C)</li> <li>● Increased lymphatic flow: smooth (GG)</li> <li>● Silicosis and coal worker's pneumoconiosis: usually nodular when active, irregular in endstage disease</li> </ul>
<p><b>2. Centrilobular branching lines (CBL)</b></p> <p><i>Bronchiolar and peribronchiolar disease (C)</i></p> <ul style="list-style-type: none"> <li>● Infectious bronchiolitis (viral, mycoplasma, aspergillus, bacterial, tuberculosis)</li> <li>● Asthma</li> <li>● Chronic bronchitis</li> <li>● Aspiration</li> <li>● Acute smoke and toxic exposure</li> <li>● Cystic fibrosis</li> <li>● Bronchioloalveolar carcinoma</li> <li>● Diffuse and interstitial lung diseases with a component of small airway involvement (Rheumatoid arthritis (RA), Sjögren's disease, panbronchiolitis, smoking-associated bronchiolar disease, hypersensitivity pneumonitis)</li> <li>● Organizing pneumonia</li> </ul> <p><i>Disease in and around the arterioles</i></p> <ul style="list-style-type: none"> <li>● Vasculitis</li> <li>● Haemorrhage</li> <li>● Fat embolism</li> <li>● Tumour thrombotic microangiopathy</li> </ul>	<p><i>Thickening of the centrilobular peribronchovascular interstitium</i></p> <ul style="list-style-type: none"> <li>● Chronic hypersensitivity pneumonitis</li> <li>● Interstitial oedema (C)</li> <li>● Interstitial lung disease (idiopathic or disease-associated) <ul style="list-style-type: none"> <li>● Idiopathic Pulmonary Fibrosis (IPF) or other causes of Usual Interstitial Pneumonia (UIP) (C)</li> <li>● Nonspecific Interstitial Pneumonia (NSIP) (C)</li> <li>● Acute interstitial pneumonia (AIP)</li> </ul> </li> <li>● Amyloidosis: smooth or irregular (C)</li> </ul>

C, common finding in this disease; GG, often associated with ground-glass opacity creating the crazy-paving pattern

### 7.2.3 Subpleural Interstitial Thickening

Because both the interlobular septa and the subpleural interstitium are part of the peripheral interstitium, subpleural interstitium thickening (SIT) occurs in the same diseases as interlobular septal thickening and is often associated with it (WEBB 1989; ZERHOUNI 1989; WEIBEL 1979) (Table 7.1) (Figs. 7.16, 7.17). Thickening can result from interstitial lung disease (Fig. 7.16a), and because a plexus of lymphatic channels is present in this area, it can also result from disease in and around the lymphatics (Fig. 7.16b). Subpleural interstitial thickening is sometimes difficult to recognise, especially in areas where the lung is in contact with the chest wall and mediastinum, but it is better appreciated when the subpleural interstitium of the lung fissures is involved; it presents as a thickening of this fissure (ZERHOUNI 1989; ZERHOUNI et al. 1985) (Fig. 7.18). When thickening is smooth, differential diagnosis





**Fig. 7.16a,b.** Subpleural interstitial thickening can be the result of interstitial lung disease (a) and of disease in and around the lymphatics (b)



**Fig. 7.17.** Irregular subpleural interstitial thickening in a patient with lung fibrosis and early honeycombing (arrows)



**Fig. 7.18.** Subpleural interstitial thickening caused by lymphangitic tumour spread. The subpleural thickening is hardly visible in the areas where the lung is in contact with the chest wall (arrowheads) but is better appreciated when the subpleural interstitium of the lung fissures is involved (white arrows). Note also the proximal peribronchovascular thickening causing the interface sign and a few septal lines

should be made with interfissural pleural effusion. This is usually easy since in most cases of subpleural interstitial thickening other compartments of the pulmonary interstitium are also involved. Subpleural interstitial thickening is a frequent finding in Idiopathic Pulmonary Fibrosis (IPF) and Usual Interstitial Pneumonia (UIP) (NISHIMURA et al. 1992), in collagen-vascular diseases and in drug-related fibrosis (COLBY and SWENSEN 1996).



Thickening of the subpleural interstitium occurs in the same diseases as interlobular septal thickening and is often associated with it.

#### 7.2.4

#### Proximal Peribronchovascular Interstitial Thickening

The peribronchovascular interstitium – also termed the axial interstitium – is a strong connective tissue sheath that surrounds the bronchi and arteries from the level of the pulmonary hila into the peripheral lung. The peripheral part that surrounds the centrilobular arteries and bronchioles was already discussed in Sect. 7.2.2.2 because when thickened this distal intralobular peribronchovascular interstitium can cause centrilobular branching lines (Fig. 7.19). More proximately and because the thickened peribronchovascular interstitium cannot be



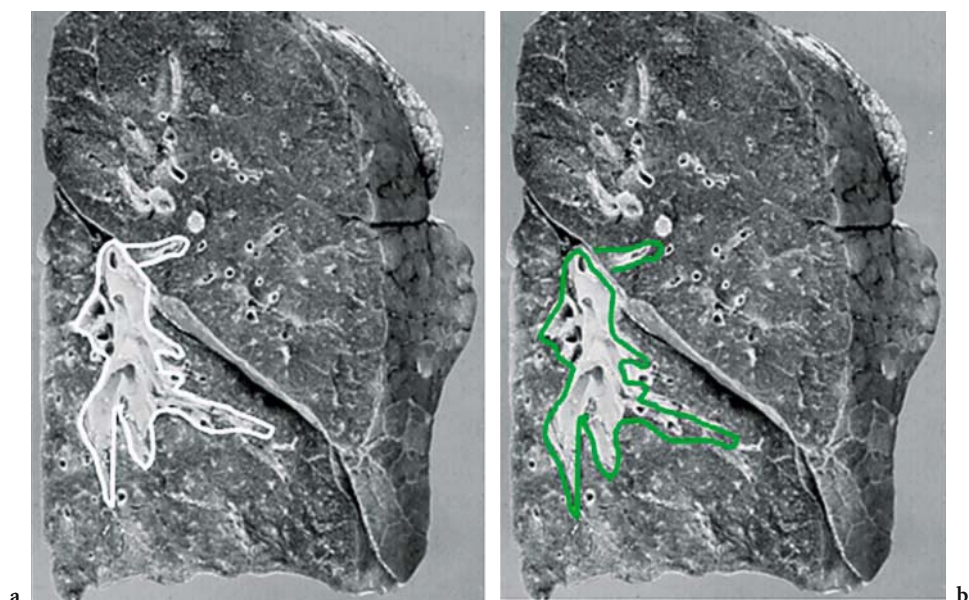


Fig. 7.19a–b. Proximal peribronchovascular thickening can be caused by thickening of the interstitium (a) and by disease in and around the lymphatics (b)

distinguished from the underlying opacity of the bronchial wall or pulmonary artery, this abnormality is often perceived on CT as an increase in bronchial wall thickness or an increase in diameter of the pulmonary artery branches (MUNK et al. 1988) and should be differentiated from pathology of the bronchial wall itself and from broadening of the pulmonary artery branches. When it is pronounced and particularly when irregular, proximal peribron-

chovascular interstitial thickening (PPIT) is usually easy to recognise, but when minimal, diagnosis can be difficult. The irregular interface between these bronchi and vessels and the aerated lung has been termed the interface sign (Fig. 7.20) (ZERHOUNI 1989; ZERHOUNI et al. 1985), a term that is also used to describe the irregular interface between the lung and the visceral pleura. PPIT can be smooth linear or irregular nodular and can occur in many diseases that cause interstitial abnormality. This can be thickening of the interstitium itself (Fig. 7.19a) (caused by fluid, infiltration with cells or with other material, and fibrous tissue) or, because also lymph channels are present, disease in and around the lymph vessels (Fig. 7.19b) (Fig. 7.20).



Fig. 7.20. Proximal peribronchovascular interstitial thickening caused by lymphangitic tumour spread. Involvement of the proximal peribronchovascular lymphatics causes irregular delineation of the vessels (arrows) and of the airways (arrowheads): the interface sign



- Proximal peribronchovascular interstitial thickening can be caused by:
  - Interstitial lung disease
  - Disease in and around the lymphatics
- Bronchial wall thickening and vascular dilatation can mimic peribronchovascular interstitial thickening.

Table 7.3 lists the diseases that are often associated with the presence of proximal peribronchovascular thickening.

Table 7.3. Proximal peri-bronchovascular thickening

1. Disease in and around the lymphatics
<ul style="list-style-type: none"> <li>● Lymphangitic tumour spread: usually smooth, sometimes nodular (C)</li> <li>● Lymphoproliferative disease: lymphoma, lymphocytic interstitial pneumonia (LIP): smooth or nodular</li> <li>● Sarcoidosis: usually nodular or irregular (C)</li> <li>● Increased lymphatic flow: smooth</li> <li>● Silicosis and coal workers pneumoconiosis: usually nodular when active, irregular in endstage disease</li> </ul>
2. Interstitium (thickening connective tissue)
<ul style="list-style-type: none"> <li>● Chronic hypersensitivity pneumonitis</li> <li>● Interstitial oedema (C)</li> <li>● Interstitial lung disease (idiopathic or disease-associated) <ul style="list-style-type: none"> <li>● Idiopathic Pulmonary Fibrosis (IPF) or other causes of Usual Interstitial Pneumonia (UIP) (C)</li> <li>● Nonspecific Interstitial Pneumonia (NSIP) (C)</li> <li>● Acute interstitial pneumonia (AIP)</li> </ul> </li> <li>● Amyloidosis: smooth or irregular (C)</li> </ul>
3. Mimics
<ul style="list-style-type: none"> <li>● Bronchial wall thickening <ul style="list-style-type: none"> <li>● Bronchitis</li> <li>● Bronchiectasis</li> </ul> </li> <li>● Dilated blood vessel <ul style="list-style-type: none"> <li>● Pulmonary arterial hypertension</li> <li>● Venous congestion</li> </ul> </li> </ul>

C, common finding in this disease.

### 7.2.5

#### Irregular Linear Opacities and Parenchymal Bands

Irregular linear opacities are thin (1–3 mm) and short irregular lines that cannot be characterised as representing septal lines, intralobular lines or as a part of the honeycombing pattern (see Sect. 7.2.6). They are also too small to be parenchymal bands

and are in contrast to the parenchymal bands not located around the bronchovascular structures. These lines are aspecific and usually represent small irregular areas of fibrosis (AUSTIN et al. 1996). Since they are sometimes present without the honeycombing pattern, they may be the first sign of lung fibrosis (Fig. 7.21). They can be seen in a variety of fibrotic lung diseases but are most frequently described in usual interstitial pneumonia (UIP) and nonspecific interstitial pneumonia (NSIP) (KIM et al. 1998; JOHKO et al. 1999b; PARK et al. 1995; KIM et al. 1999).

The term “parenchymal band” has been used to describe a nontapering linear opacity, usually several millimetres in thickness, and from 2 to 5 cm in length crossing the pulmonary parenchyma (Fig. 7.22). Parenchymal bands can be caused by atelectasis, interstitial thickening (which can be caused by thickening of the interstitial connective tissue or by diseases in and around the lymphatics) and by pulmonary fibrosis. These parenchymal bands are often located in the lung periphery and are contiguous with the pleural surface, which may also be thickened and retracted inward. These bands may also be caused by peribronchovascular fibrosis surrounded by infiltrated and atelectatic lung tissue. When caused by peribronchovascular fibrosis, these bands are often several millimeters thick, irregular in contour and associated with a distortion of the adjacent lung parenchyma and the bronchovascu-

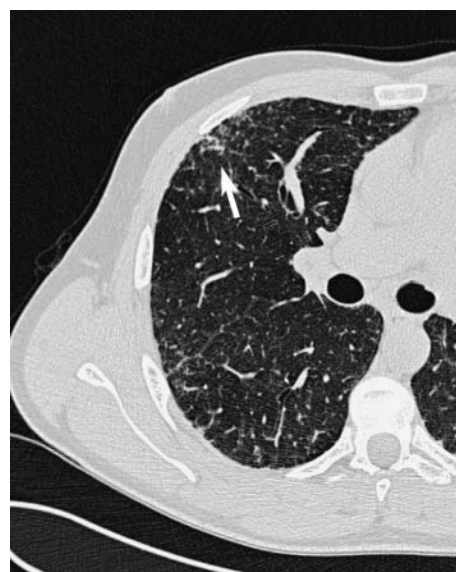
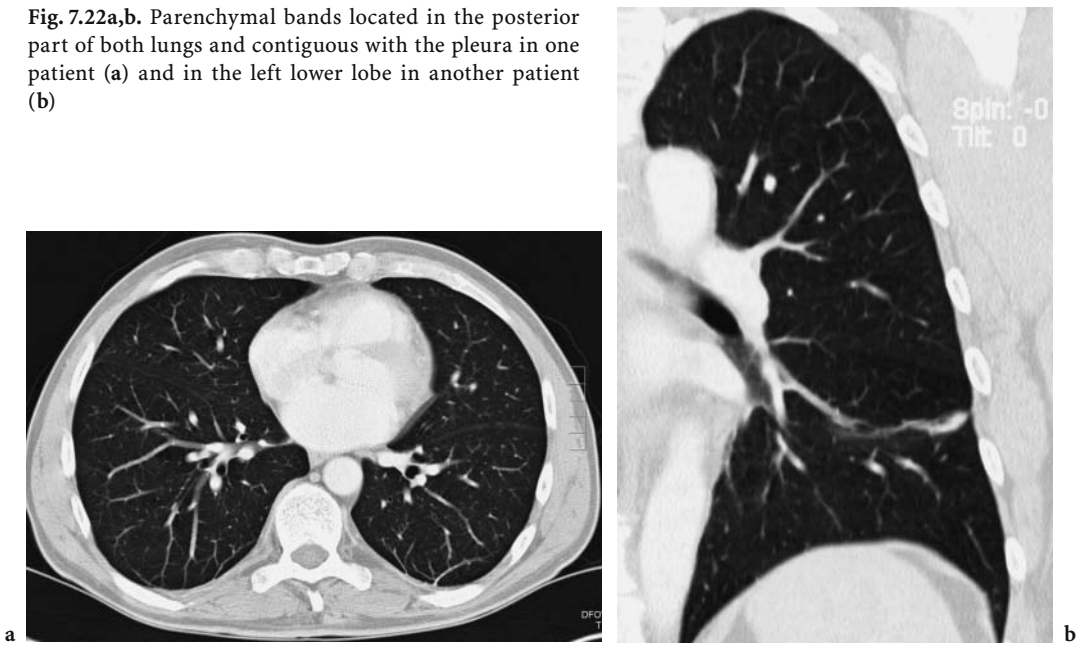


Fig. 7.21. Small irregular linear opacities in a patient with pulmonary fibrosis (arrows)

Fig. 7.22a,b. Parenchymal bands located in the posterior part of both lungs and contiguous with the pleura in one patient (a) and in the left lower lobe in another patient (b)



lar structures. Parenchymal bands have also been described as a result of organising pneumonia and then probably result from a combination of granulation tissue polyps in the small airways and the airspaces and some atelectasis of the surrounding lung (MURPHY et al. 1999) (Fig. 7.23). Contiguous thickened interlobular septa (AKIRA et al. 1990) may look very similar to these parenchymal bands, although the peribronchovascular character is lacking. Since these contiguous thickened interlobular septa have

a different differential diagnosis which is similar to that of the septal thickening, it is important, as mentioned earlier, to differentiate them from each other and not to use the term “parenchymal band” when the linear opacities are clearly caused by contiguous septal lines (AKIRA et al. 1990; LYNCH et al. 1988; IM et al. 1993; TRAILL et al. 1997; ABERLE et al. 1988).

Table 7.4 shows the most frequent causes of parenchymal bands.

Table 7.4. Most common causes of parenchymal bands

● Asbestos-related lung and pleural disease (basal predominance)
● Sarcoidosis (axial predominance)
● Silicosis and coal workers’ pneumoconiosis
● Tuberculosis scarring (upper lung predominance)
● Organising pneumonia (less common, may be reversible)



Fig. 7.23. Parenchymal bands (arrows) in a patient with organising pneumonia. The irregular contour and the distortion of the adjacent lung parenchyma and bronchovascular structures indicate the presence of fibrosis

### 7.2.6 Honeycombing Pattern

As mentioned above, irregular thickening of the septal and intralobular lines and the subpleural and peribronchovascular interstitium may indicate the development of pulmonary fibrosis. When this



fibrosis becomes extensive and when it causes disruption of the alveoli and of the bronchioles (bronchiolectasis), a characteristic pattern is produced: honeycombing or honeycomb lung.

Pathologically, honeycombing is defined by the presence of small air-containing cystic spaces, generally lined by bronchiolar epithelium with thick walls composed of dense fibrous tissue.

On CT, the pattern is also rather characteristic (WEBB et al. 1988; MULLER et al. 1986), consisting of a mixture of irregular lines and lucent areas that together form cystic spaces varying in size from several millimetres to several centimetres (Fig. 7.24). Usually the cystic spaces average 1 cm in diameter while the walls have thickness of 1–3 mm. This pattern may resemble the intralobular reticular pattern (Figs. 7.25, 7.8) but can be differentiated from it in that in honeycombing the areas between the lines (that are irregular) contain only air and hence appear more lucent than normal lung tissue, creating the cystic pattern. In addition, especially in advanced fibrosis, the cystic spaces are usually slightly larger than the hypodense areas within the intralobular reticular pattern, although they are smaller than the reticular pattern seen when the interlobular septa are thickened (ZERHOUNI et al. 1985). Adjacent honeycomb cysts typically share walls. When located in the subpleural



Fig. 7.24. Honeycombing pattern in the subpleural, posterior and lateral part of the right lower lobe in a patient with idiopathic pulmonary fibrosis. Irregular lines with only air in between are observed

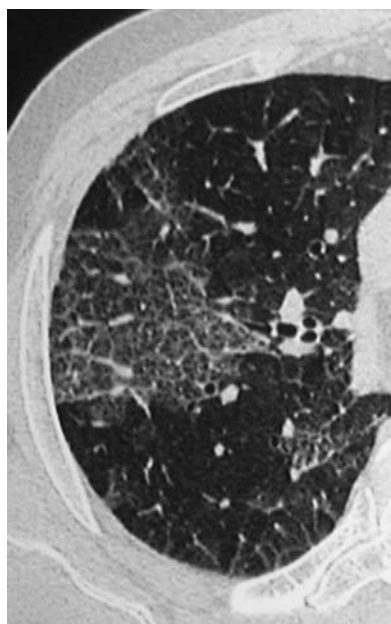


Fig. 7.25. Intralobular reticular pattern in a patient with NSIP. This pattern can be differentiated from the honeycomb pattern because the linear opacities are regular and the areas between the lines have a lung or increased density. In addition, there are no signs of lung destruction and the spaces between the lines are usually a little smaller than the hypodense areas within the honeycombing pattern

area – as is often the case – honeycomb cysts typically occur in several contiguous layers, a feature that in most cases allows differentiation of these honeycomb cysts from paraseptal emphysema. In paraseptal emphysema, subpleural hypodense areas usually occur in a single layer. The difference between honeycombing and paraseptal emphysema was explained in more detail in Chap. 5.

As mentioned earlier, honeycombing is often associated with other findings of pulmonary fibrosis: irregular septal and intralobular lines (both the reticular pattern and the centrilobular branching lines), irregular linear opacities not characterised as septal or intralobular lines, irregular subpleural and peribronchovascular thickening, lung distortion with traction bronchiectasis and bronchiolectasis. In patients with CT signs of linear opacities and reticulation, the presence of honeycombing indicates that fibrosis is present and these linear opacities and reticulation may also stem from fibrosis. Table 7.5 lists the most frequent causes of honeycomb pattern in the lung. The distribution pattern of honeycombing in the lung can be helpful in the diagnosis of the cause of the pulmonary fibrosis (Table 7.7b)



Table 7.5. Most frequent causes of the honeycombing pattern

Common:
<ul style="list-style-type: none"><li>● Usual interstitial pneumonia (UIP): idiopathic pulmonary fibrosis (IPF) and disease-associated UIP</li><li>● Asbestosis</li><li>● Hypersensitivity pneumonitis (chronic)</li></ul>
Uncommon:
<ul style="list-style-type: none"><li>● Sarcoidosis</li><li>● Nonspecific interstitial pneumonia (NSIP)</li><li>● Acute interstitial pneumonia (AIP)</li><li>● Desquamative interstitial pneumonia (DIP)</li><li>● Organising pneumonia</li><li>● Silicosis and coal workers' pneumoconiosis</li></ul>

7.3  
Distribution Patterns

The appearance of linear opacities (septal lines and intralobular lines) crossing the lung parenchyma on a CT of the lungs, suggests that the pulmonary interstitium is thickened. When subpleural and peribronchovascular thickening is also present, interstitial broadening becomes very likely. This broadening can be caused by infiltration of the interstitial tissues by fluid, cells or other material and hence many diseases can be responsible for these changes.

The first question that should be raised to narrow the differential diagnosis list is whether the involvement of the interstitium seems predominantly located in and around the lymphatics, i.e. whether there is predominantly a (peri)lymphatic distribution of disease. Arguments for a (peri)lymphatic distribution can be found in and around the secondary pulmonary lobule. A (peri)lymphatic distribution is suggested when septal lines in combination with centrilobular branching lines are the most striking finding.

On the other hand, when septal lines are associated with the presence of a reticular pattern of intralobular lines, the distribution pattern very likely is not (peri)lymphatic and a more uniform thickening of the interstitial connective tissue septa is likely causing the CT changes.

It should be remembered, however, that a combination of lines that mimic septal lines and an intralobular reticular pattern can also be seen when there is a deposition of material within the airspaces at the borders of the acini and secondary pulmonary lob-

Table 7.6. Regional distribution of lung diseases that can cause a linear pattern

Upper lung versus Lower lung versus Diffuse
<p><b>Upper:</b> sarcoidosis, silicosis and coal workers' pneumoconiosis, tuberculosis, respiratory bronchiolitis, cystic fibrosis</p> <p><b>Lower:</b> oedema, usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), desquamative interstitial pneumonia (DIP), organising pneumonia, alveolar haemorrhage</p> <p><b>Diffuse:</b> chronic hypersensitivity pneumonitis, diffuse pneumonia, lymphangitic spread of tumour, sarcoidosis</p>
Central lung versus peripheral lung
<p><b>Central:</b> sarcoidosis, silicosis and coal workers' pneumoconiosis, lymphangitic spread of tumour, alveolar proteinosis, large airways disease</p> <p><b>Peripheral:</b> usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), chronic eosinophilic pneumonia, organising pneumonia, acute interstitial pneumonia (AIP), desquamative interstitial pneumonia (DIP), hypersensitivity pneumonitis, small airways disease</p>
Posterior versus anterior lung
<p><b>Posterior:</b> pulmonary oedema, adult respiratory distress syndrome (ARDS), usual interstitial pneumonia (UIP) (idiopathic pulmonary fibrosis (IPF) and disease-associated UIP), asbestosis, nonspecific interstitial pneumonia (NSIP), silicosis and coal workers' pneumoconiosis, sarcoidosis, chronic hypersensitivity pneumonitis</p> <p><b>Anterior:</b> post-adult respiratory distress (ARDS) fibrosis</p>
Can be unilateral or asymmetric
Pneumonia, lymphangitic spread of tumour, sarcoidosis

ules. Unless there is associated interstitial involvement, peribronchovascular and subpleural thickening need not be present in this situation.

When the presence of centrilobular branching lines is the most striking finding and when no septal lines are seen, the disease very likely shows an airway distribution pattern, especially when the tree in bud pattern can be identified. Subpleural thickening is usually also absent. However, peribronchovascular thickening surrounding the larger proximal bronchial structures may be observed. The latter is not caused by thickening of the peribronchovascular interstitium, but is related to the inflammatory thickening of the wall of the large

proximal bronchi since large airway disease often accompanies small airway involvement.

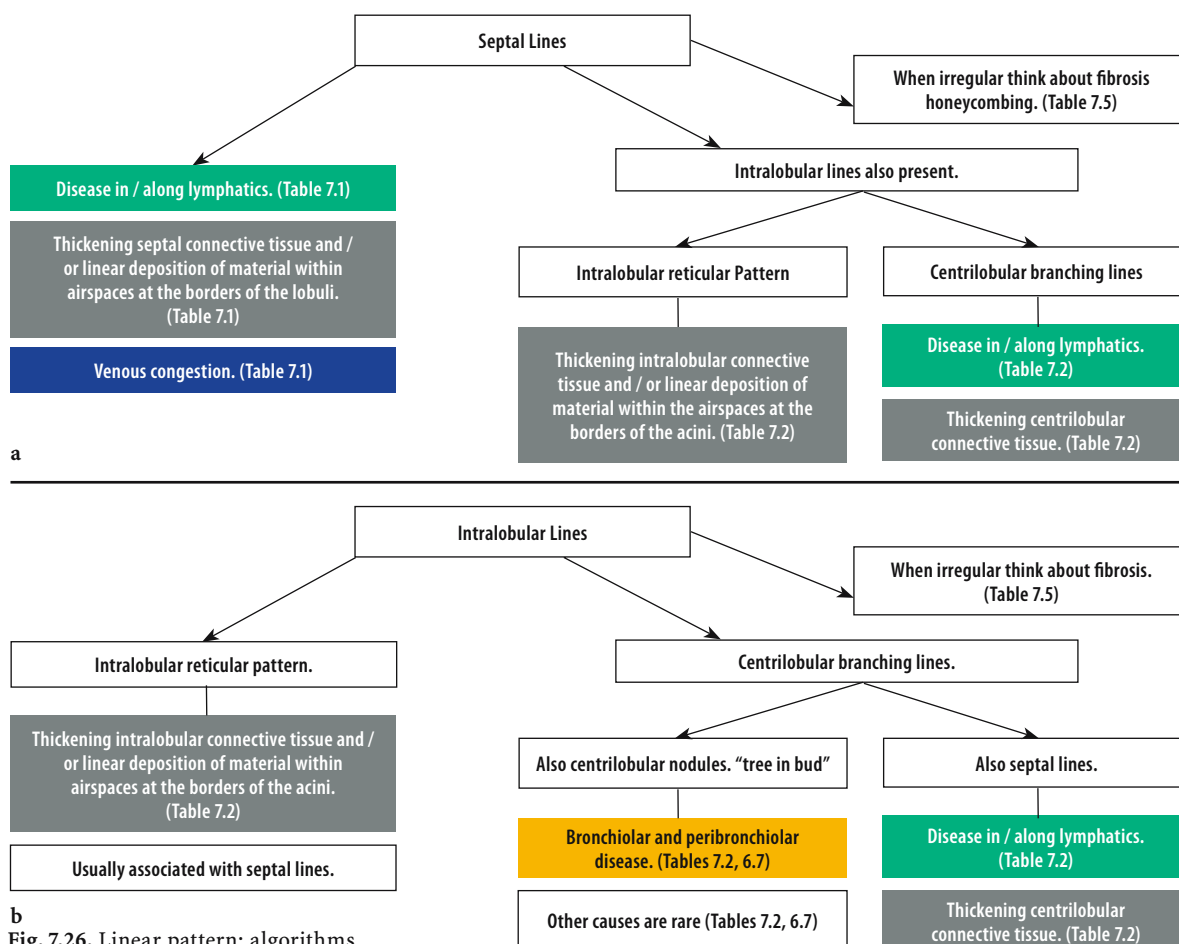
Centrilobular branching lines can also be caused by lung pathology that is related to the blood vessels, i.e. the disease is distributed through these blood vessels and manifests itself predominantly in and around these vessels (vascular distribution). As in the airway distribution, subpleural lines are usually absent, but broadening of the larger blood vessels may mimic peribronchovascular thickening.

Diagnostic algorithms starting from either septal lines or intralobular lines as the dominant finding are respectively shown in Figures 7.26a and 7.26b. Linear opacities are often seen together with ground-glass opacities creating the crazy-paving pattern. This crazy-paving pattern can be seen when the lines are caused by deposition of material within in the alveolar spaces, which is not only responsible for the lines, but also for the slight increase in long density. Also, when the lines are caused by thickening of the interstitial connective tissue septa, a crazy-paving pattern is often present because very often the parenchymatous interstitium is also involved, causing the ground-glass opacity part of the pattern.

The differential diagnosis list of causes of linear opacities on (HR)CT of the lung can be further reduced by studying the regional distribution of these linear opacities: Tables 7.6 and 7.7 show the regional distribution of diseases that often show a linear appearance pattern (Fig. 7.26).

Table 7.7. Regional distribution of the honeycombing pattern

Subpleural, lower lobe and posterior:
<ul style="list-style-type: none"> <li>● Usual interstitial pneumonia (UIP): idiopathic pulmonary fibrosis (IPF) and disease-associated UIP (may extend towards the central and upper lung)</li> <li>● Asbestosis</li> <li>● Hypersensitivity pneumonitis (also central and upper lung)</li> </ul>
Central and upper lung:
<ul style="list-style-type: none"> <li>● Sarcoidosis (sometimes extending to the subpleural, posterior lower lobe)</li> <li>● Hypersensitivity pneumonitis (also subpleural, lower lobe and posterior)</li> </ul>



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- Murphy JM, Schnyder P, Verschakelen J, Leuenberger P, Flower CD (1999) Linear opacities on HRCT in bronchiolitis obliterans organising pneumonia. *Eur Radiol* 9:1813–1817
- Nishimura K, Kitaichi M, Izumi T et al (1992) Usual interstitial pneumonia: histologic correlation with high-resolution CT. *Radiology* 182:337–342
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- Reid L, Simon G (1958) The peripheral pattern in the normal bronchogram and its relation to peripheral pulmonary anatomy. *Thorax* 13:103–109
- Stein MG, Mayo J, Müller N et al (1987) Pulmonary lymphangitic spread of carcinoma: appearance on CT scans. *Radiology* 162:371–375
- Swensen SJ, Aughenbaugh GL, Brown LR (1989) High-resolution computed tomography of the lung. *Mayo Clin Proc* 64:1284–1294
- Traill ZC, Maskell GF, Gleeson FV (1997) High-resolution CT findings of pulmonary sarcoidosis. *AJR Am J Roentgenol* 168:1557–1660
- Ujita M, Renzoni EA, Veeraghavan et al (2004) Organising pneumonia: perilobular pattern at thin section CT. *Radiology* 232(2): 757–761
- Webb WR (1989) High-resolution CT of the lung parenchyma. *Radiol Clin North Am* 27:1085–1097
- Webb WR, Stein MG, Finkbeiner WE et al (1988) Normal and diseased isolated lungs: high-resolution CT. *Radiology* 166:81–87
- Weibel ER (1979) Looking into the lung: what can it tell us? *AJR Am J Roentgenol* 133:1021–1031
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- Zerhouni EA, Naidich DP, Stitik FP et al (1985) Computed tomography of the pulmonary parenchyma: part 2. Interstitial disease. *J Thorac Imaging* 1:54–64

# Case Study

WALTER DE WEVER and JOHNY A. VERSCHAKELLEN

## Introduction

In this chapter, the most common and characteristic features of several diseases that affect the lungs are demonstrated. Some diseases show a typical presentation while others are less typical or show only a part of their spectrum of CT signs. These cases are in the first place intended for exercising pattern recognition and will also help to understand why diseases appear as they do on CT.

Each case starts with a short description of the pathological features seen on the CT images. Then a short review of the disease is given with, when appropriate, a short description of the histopathological changes that may be responsible for the CT signs.

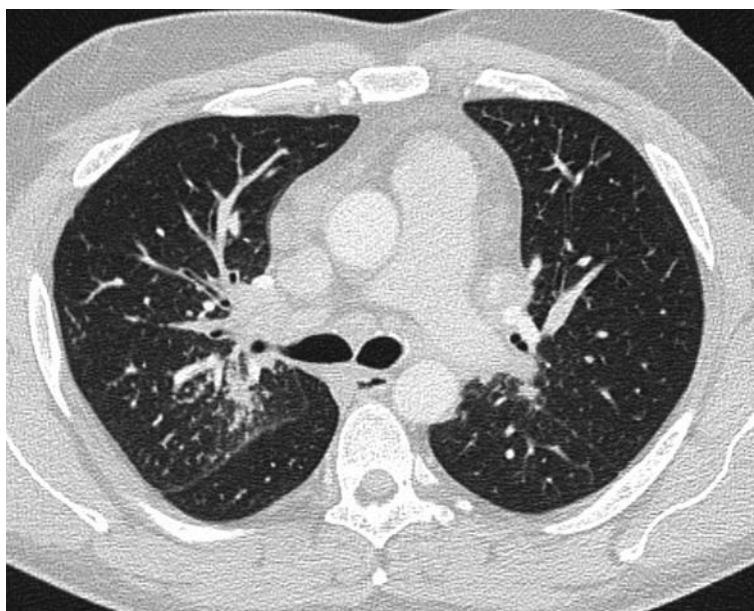
This is followed by a description of the most common CT features of that disease (that are not necessarily all illustrated in the case that is shown). This description is organised into three paragraphs: (1) the appearance patterns, (2) the distribution patterns, and (3) when appropriate, a short review of often-occurring associated findings.

Table 8.1 shows the diseases that are illustrated in this chapter.

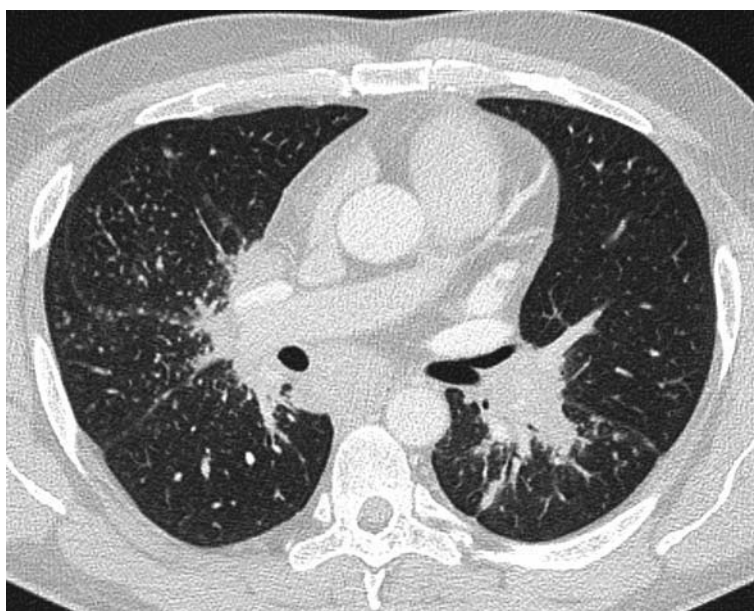
**Table 8.1.** shows the diseases that are illustrated in this chapter

Disease	Case number
Acute interstitial pneumonia (AIP)	18
Adult (acute) respiratory distress syndrome (ARDS)	3
Allergic bronchopulmonary aspergillosis (ABPA)	29
Angioinvasive pulmonary aspergillosis	14
Bronchiolitis obliterans	20
Bronchioloalveolar carcinoma (BAC)	4, 5
Chronic eosinophilic pneumonia	37
Churg-Strauss syndrome	31
Coal workers' pneumoconiosis (CWP)	2
Cryptogenic organising pneumonia (COP)	6
Dermatomyositis (usual interstitial pneumonia, UIP)	8
Desquamative interstitial pneumonia (DIP)	40
Drug-induced pneumonitis	39
Emphysema (bullous)	11
Emphysema (mild centrilobular)	19
Emphysema (panlobular)	28
Emphysema (paraseptal)	35
Hypersensitivity pneumonitis	9, 21, 32
Idiopathic pulmonary fibrosis (IPF) (usual interstitial pneumonia, UIP)	13, 23
Infectious bronchiolitis and bronchopneumonia	7
Infectious bronchiolitis with tree-in-bud pattern	22
Lymphangiomyomatosis (LAM)	15
Lymphangitic spread of tumour	16
Lymphocytic interstitial pneumonia (LIP) associated with Sjögren disease	24
Mosaic pattern and air trapping secondary to small airway narrowing	36
Mosaic pattern secondary to obstruction of small arteries	34
Nonspecific interstitial pneumonia (NSIP)	fibrotic 26, cellular 33
<i>Pneumocystis jiroveci</i> pneumonia ( <i>Pneumocystis carinii</i> pneumonia)	30
Pulmonary haemorrhage	27
Pulmonary Langerhans cell histiocytosis	10, 12
Respiratory bronchiolitis interstitial lung disease (RB-ILD)	17
Sarcoidosis	1
Scleroderma	25
Wegener's granulomatosis (WG)	38





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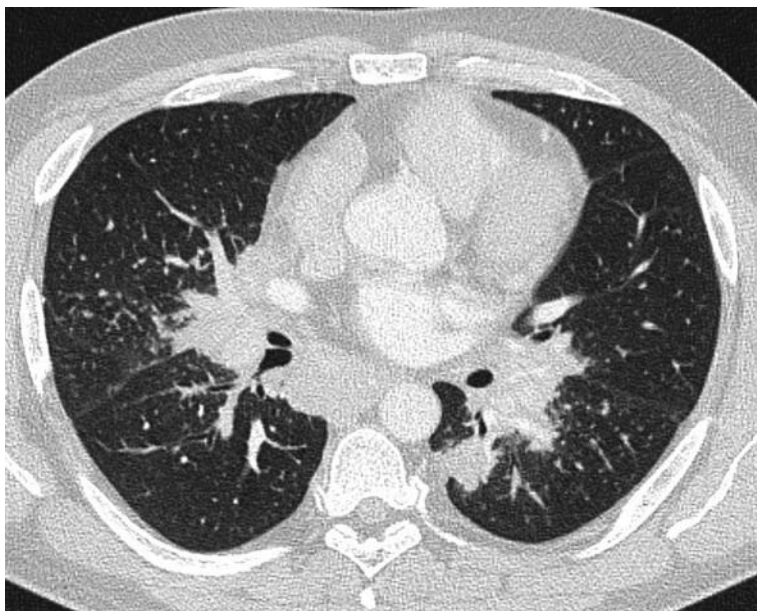
**Case 1**

CT shows multiple small dense nodules in both lungs located predominantly in the middle lung regions. These nodules have a (peri)lymphatic distribution pattern: nodular thickening of the fissures and nodular delineation of the central bronchovascular structures. In addition, irregular dense opacities are seen that surround the axial bronchovascular tree.

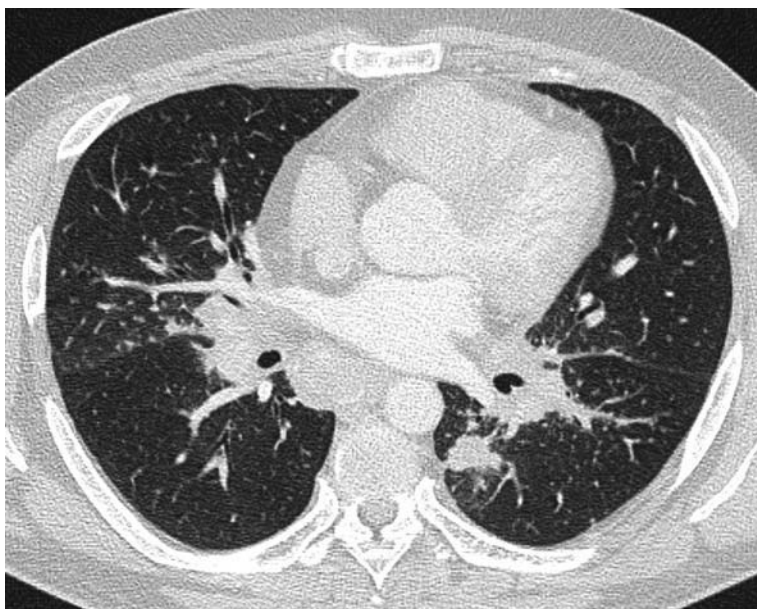
There are enlarged lymph nodes with central calcification in the mediastinum and in both hili.

**Diagnosis****Sarcoidosis**

Sarcoidosis is a systemic disorder of unknown cause, characterised by the presence of non-necrotising granulomatous inflammation in a lymphatic and perilymphatic distribution. These granulomas may resolve spontaneously, but may



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also conglomerate to irregular peribronchovascular masses and progress to fibrosis. The granulomas are well formed, with histiocytes centrally, surrounded by a rim of lymphocytes and mononuclear cells.

## CT Findings

### Appearance patterns:

- Nodular:
  - Small, well-defined nodules
  - Soft-tissue density (interstitial nodules)
- Conglomeration of nodules into larger nodules, consolidation or masses, sometimes ground-glass
- Decreased attenuation:
  - Mosaic perfusion
  - Air trapping
- Advanced disease: fibrosis with irregular septal thickening, honeycombing, irregular fibrotic masses

### Distribution patterns:

- (Peri)lymphatic: predominantly peribronchovascular also subpleural, septal and centrilobular
- Central lung and upper lobes
- Patchy

### Associated findings:

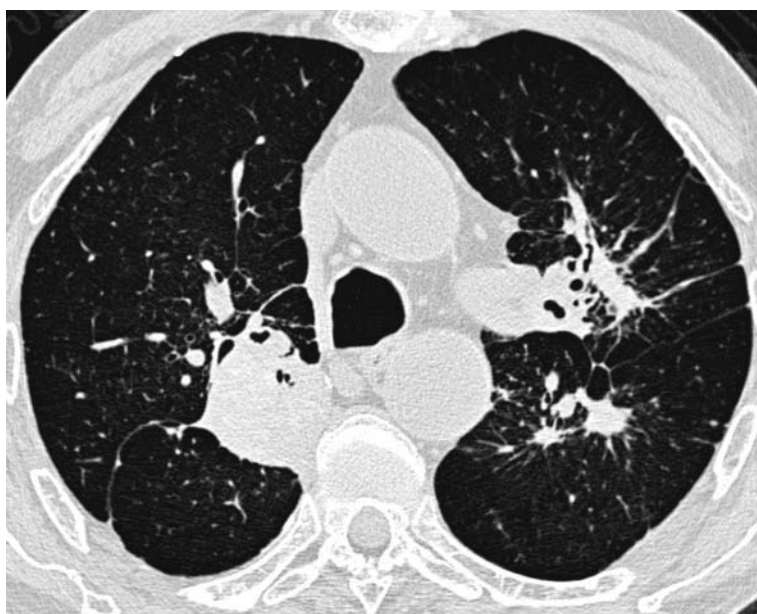
- Mediastinal and hilar lymph node enlargement, usually symmetrical, sometimes calcified (egg shell)

## References

- Chiles C (2002) Imaging features of thoracic sarcoidosis. *Semin Roentgenol* 37:82–93
- Nishimura K, Itoh H, Kitaichi M et al (1993) Pulmonary sarcoidosis: correlation of CT and histopathologic findings. *Radiology* 189:105–109



2.1



2.2

## Case 2

Small well-defined nodules can be seen in the middle and upper lung regions of both lungs. The distribution of the nodules is more or less symmetrical and most nodules are located near the centre of the secondary pulmonary lobules, although some nodules have a subpleural location. There are also areas of consolidation and irregular masses due to fibrosis in the upper lobes.

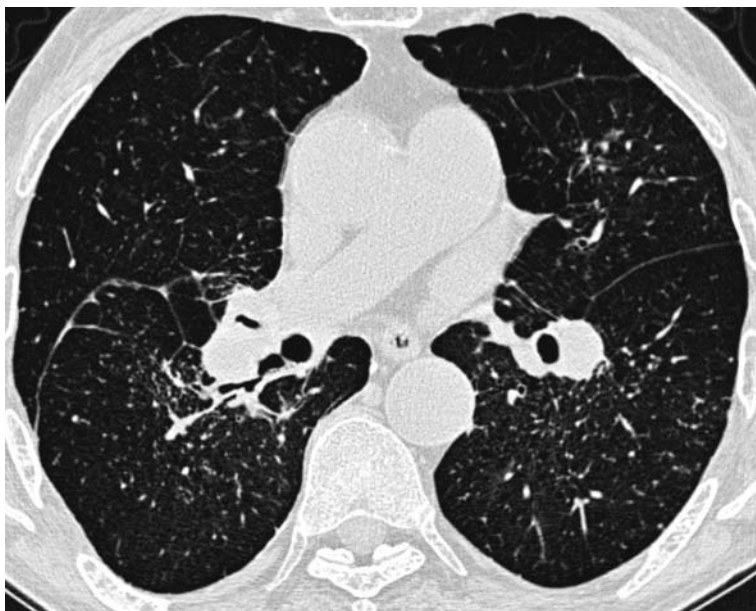
## Diagnosis

### Coal workers' pneumoconiosis

Coal workers' pneumoconiosis (CWP) results from the inhalation of coal dust. A history of significant exposure (10 years or more) is necessary in order to consider the diagnosis. Histologically, the characteristic lesion of CWP is the so-called coal macula, which consists of a focal accumulation of coal dust surrounded by a small amount of fibrosis.



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## CT Findings

### Appearance patterns:

- Nodular:
  - Small ill-defined or well-defined nodules (2–5 mm in diameter)
  - Soft-tissue density (interstitial nodules)
- Conglomeration of nodules into larger nodules, consolidation or masses
- Advanced disease: irregular fibrotic masses surrounded by linear opacities and paracardiac emphysema

### Distribution patterns:

- (Peri)lymphatic distribution: subpleural and centrilobular, also septal
- Diffuse with (right) upper lobe and posterior lung predominance

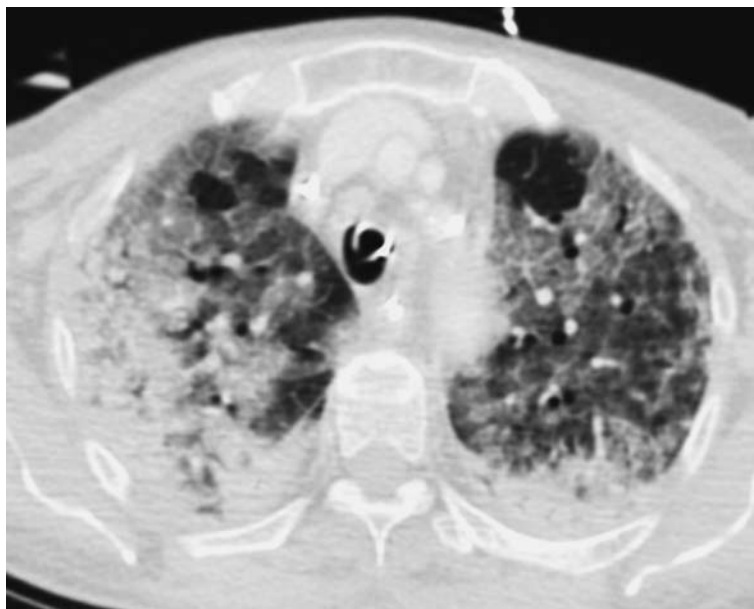
### Associated findings:

- Masses can calcify and contain areas of necrosis
- Focal centrilobular emphysema
- Mediastinal lymph node enlargement, often calcified

## References

- Ooi GC, Tsang KW, Cheung TF et al (2003) Silicosis in 76 men: qualitative and quantitative CT evaluation-clinical-radiologic correlation study. *Radiology* 228:816–825
- Talini D, Paggiaro PL, Falaschi F et al (1995) Chest radiograph and high resolution computed tomography in the evaluation of workers exposed to silica dust: relation with functional findings. *Occup Environ Med* 52:262–267





3.1



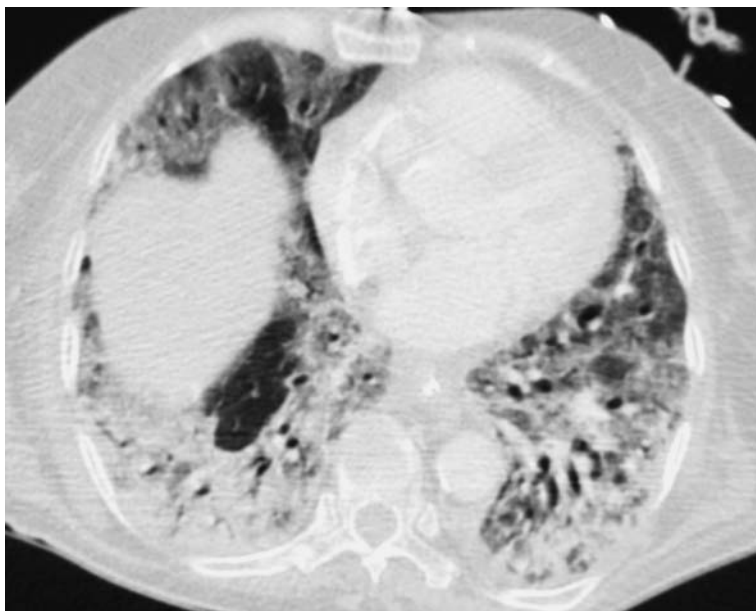
3.2

**Case 3**

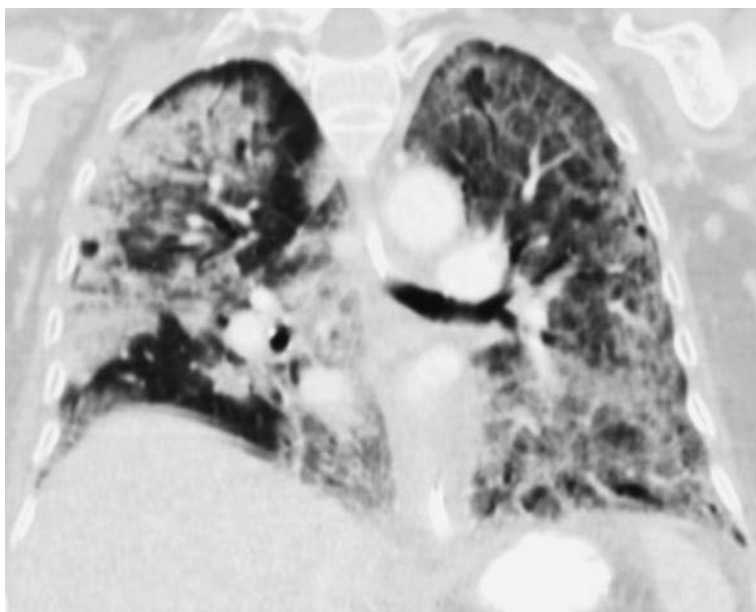
There is a diffuse and bilateral increase in lung attenuation (ground-glass opacity) with areas of consolidation with an air bronchogram especially in the dependent lung. In some regions, a faint linear pattern is associated with the ground-glass opacity, creating a crazy-paving appearance.

**Diagnosis****Adult respiratory distress syndrome**

Adult respiratory distress syndrome (ARDS) is a devastating syndrome of lung injury following known risk factors, with a persistently high mortal-



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ity. The American-European Consensus Conference definition of ARDS requires the acute onset of bilateral chest radiographic infiltrates with hypoxemia but without left atrial hypertension. Diffuse alveolar damage is the histopathological finding that corresponds to the clinical entity of ARDS.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (partial filling of airspaces)
  - Consolidation (complete filling of airspaces)
  - Crazy-paving

### Distribution patterns:

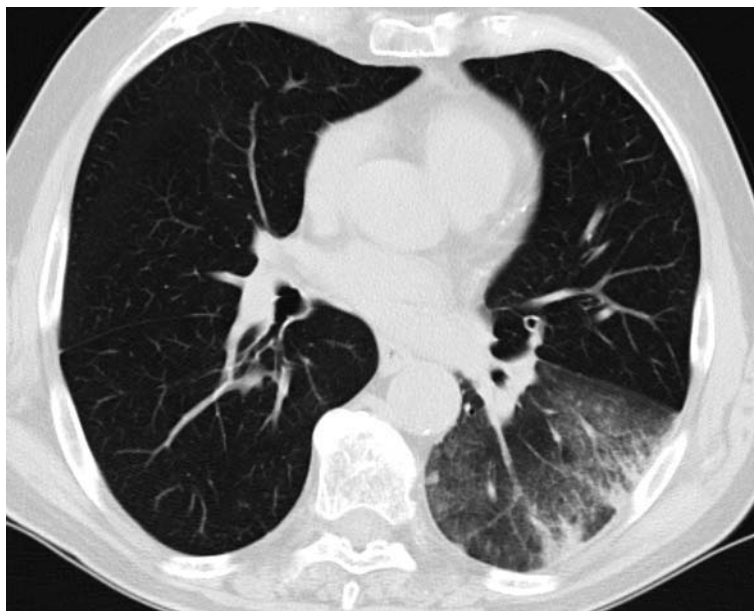
- Interstitium, airspace
- Diffuse or patchy
- More pronounced in the dependent lung areas

### Associated findings:

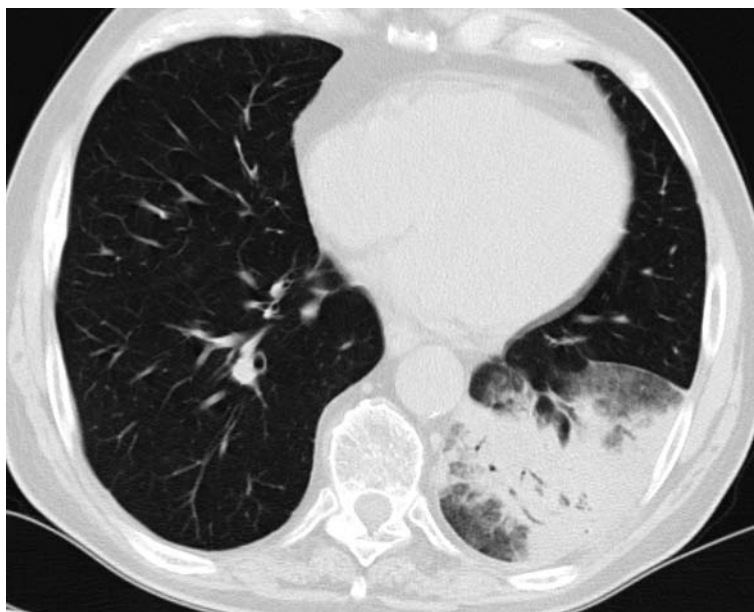
- Advanced disease: architectural distortion, traction bronchiectasis
- Residual findings: areas of hypoattenuation, lung cysts, reticular pattern, and associated parenchymal distortion occurring mainly in the nondependent lung

## References

- Caironi P, Carlesso E, Gattioni L (2006) Radiological imaging in acute lung injury and acute respiratory distress syndrome. *Semin Respir Crit Care Med* 27:404–415
- Morrison RJ, Bidani A (2002) Acute respiratory distress syndrome epidemiology and pathophysiology. *Chest Surg Clin N Am* 12:301–323



4.1



4.2

## Case 4

CT shows ground-glass opacity and consolidation with air bronchogram involving almost the entire left lower lobe and delineated by the major fissure.

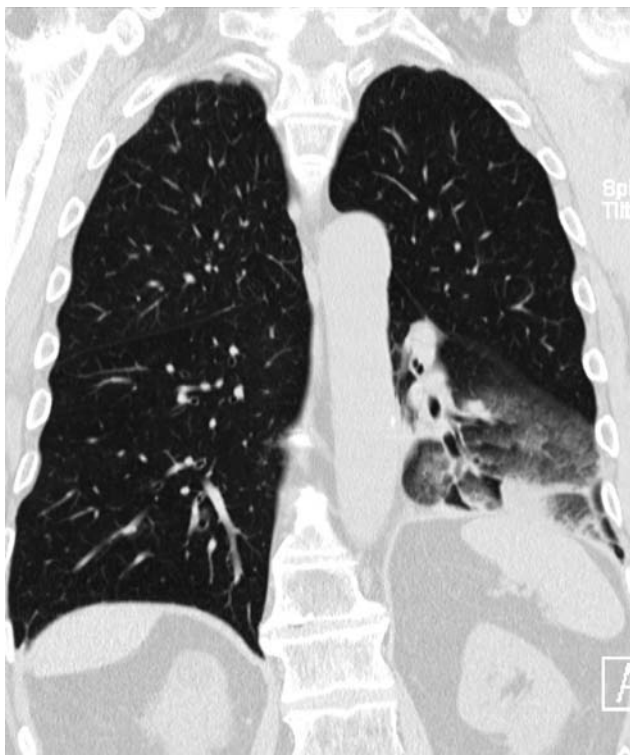
### Diagnosis

#### Bronchioloalveolar carcinoma

Bronchioloalveolar carcinoma (BAC) is one of the four histological subtypes of adenocarcinoma. This malignant tumour grows in a lepidic fashion along

the alveolar septa without invading alveolar walls. Ground-glass opacity and lung consolidation develop because the air in the airspaces is partially or totally replaced by tumour cells. In this way bronchioloalveolar carcinoma can mimic other diseases such as pulmonary infection that also cause filling of the airspaces.

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## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (mucinous BAC)
  - Consolidation
  - Crazy-paving (mucinous BAC)
- Nodular:
  - Ill-defined or well-defined
  - Ground-glass or soft-tissue density (airspace nodule)
- Linear:
  - Centrilobular branching lines

### Distribution patterns:

- Airspace
- Ground-glass and consolidation: lobar, patchy
- Nodules: centrilobular

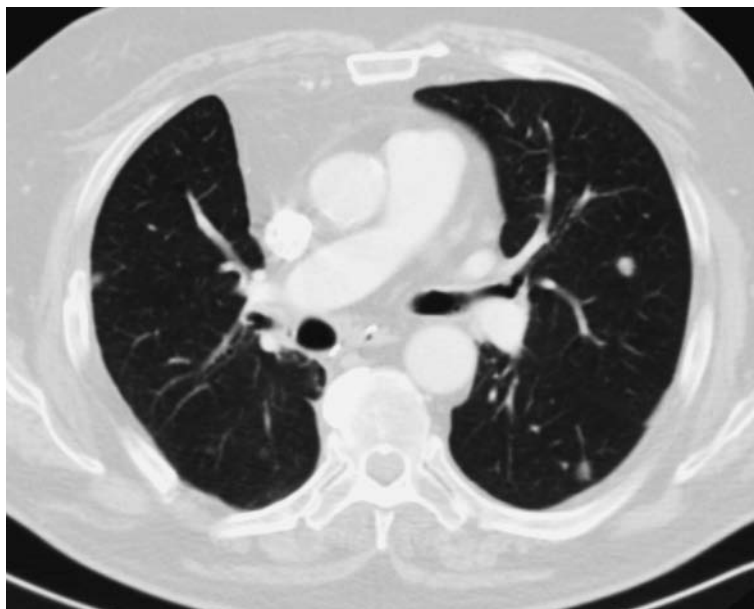
### Associated findings:

- CT angiogram sign on enhanced scan (aspecific)
- Features of haematogenous metastases

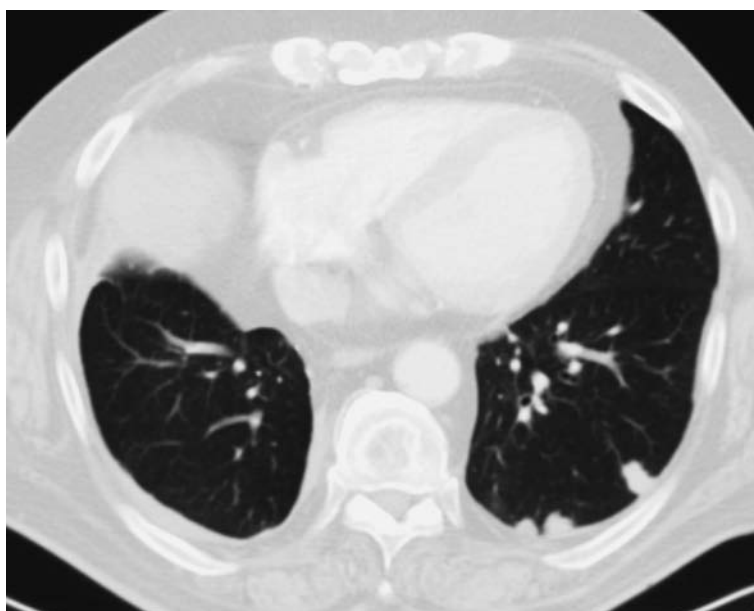
## References

- Akira M, Ataqi S, Kawahara M et al (1999) High-resolution CT findings of diffuse bronchioloalveolar carcinoma in 38 patients. *AJR Am J Roentgenol* 173:1623–1629
- Gaeta M, Caruso R, Barone M et al (1998) Ground-glass attenuation in nodular bronchioloalveolar carcinoma: CT patterns and prognostic value. *J Comput Assist Tomogr* 22:215–219





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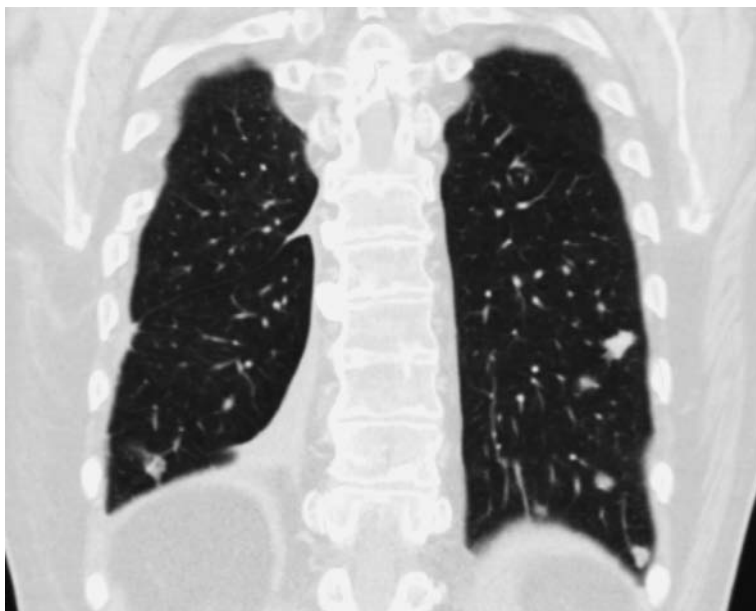
**Case 5**

Multiple well-defined nodules are seen in both lungs. Most nodules are separated from the pleural surface by a distance of 5–10 mm, indicating a centrilobular distribution. Some larger nodules in the left lower lobe touch the pleura.

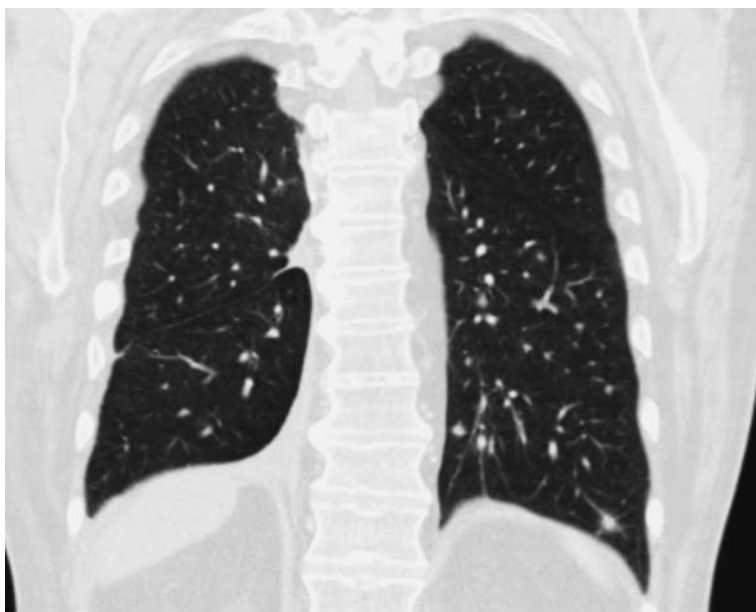
**Diagnosis****Bronchioloalveolar Carcinoma**

BAC is one of the four histological subtypes of adenocarcinoma. This malignant tumour grows in a lepidic fashion along the alveolar septa without invading alveolar walls.

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## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (mucinous BAL)
  - Consolidation
  - Crazy-paving (mucinous BAL)
- Nodular:
  - Ill-defined or well-defined
  - Ground-glass or soft tissue density (airspace nodule)
- Linear:
  - Centrilobular branching lines

### Distribution patterns:

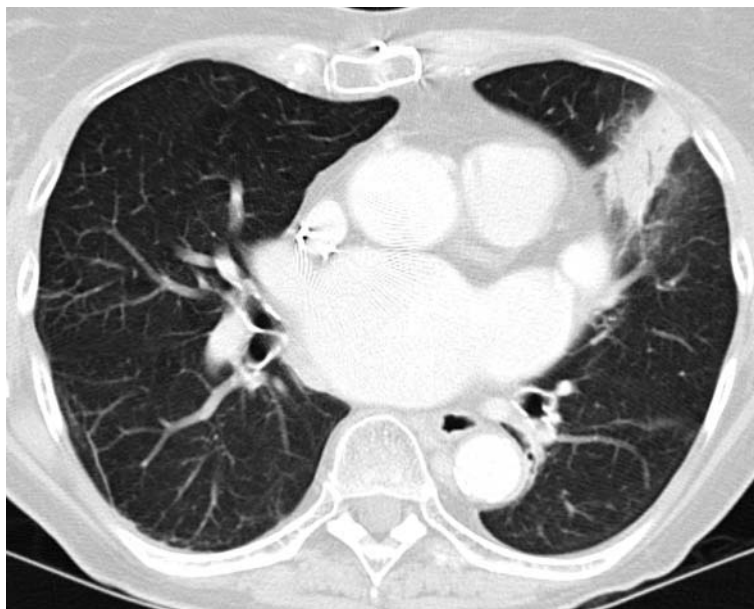
- Airspace
- Ground-glass and consolidation: lobar, patchy
- Nodules: centrilobular

### Associated findings:

- CT angiogram sign on enhanced scan (aspecific)
- Features of haematogenous metastases

## References

- Akira M, Ataqi S, Kawahara M et al (1999) High-resolution CT findings of diffuse bronchioloalveolar carcinoma in 38 patients. *AJR Am J Roentgenol* 173:1623–1629
- Gaeta M, Caruso R, Barone M et al (1998) Ground-glass attenuation in nodular bronchioloalveolar carcinoma: CT patterns and prognostic value. *J Comput Assist Tomogr* 22:215–219



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## Case 6

Well-defined areas of lung consolidation (some of them are surrounded by ground-glass opacity, some show an air bronchogram) are seen in both lungs in a peripheral subpleural distribution (air bronchogram).

### Diagnosis

#### Cryptogenic organising pneumonia

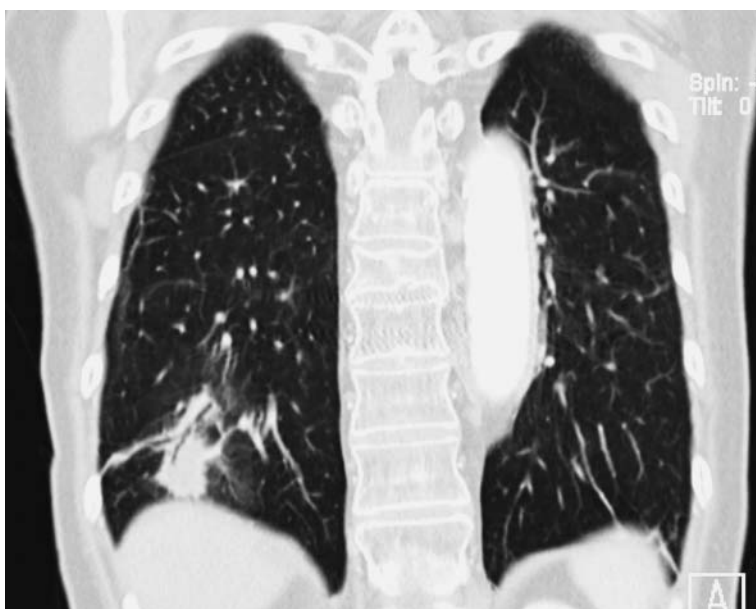
Cryptogenic organising pneumonia (COP) has also been called idiopathic bronchiolitis obliterans or-

ganising pneumonia (idiopathic BOOP). It is a clinical-pathological entity that is part of the idiopathic interstitial pneumonia classification of the 2002 American Thoracic Society/European Respiratory Society (ATS/ERS). Organising pneumonia is not always idiopathic and can also be associated with infection, certain connective tissue diseases, and chronic eosinophilic pneumonia; it can be seen following irradiation or may stem from a drug reaction (disease-associated organising pneumonia, BOOP reaction). Histologically, organising pneumonia is characterised by the presence of polypoid plugs

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of loose granulation tissue predominantly involving the airspaces but often also in the lumen of the small airways.

## CT Findings

### Appearance patterns:

- Increased attenuation (airspace component of disease):
  - Consolidation
  - Ground-glass
  - Crazy-paving
- Nodular (small airway component):
  - Small well- or ill-defined nodules
  - Soft-tissue or ground-glass density (airspace nodules)
  - Tree-in-bud
  - Mass (less common)
- Linear:
  - Centrilobular branching lines (small airway component of disease)
  - Tree-in-bud (small airway component of disease)
  - Parenchymal band (less common)
  - Septal lines (less common)
  - Perilobular (less common)

### Distribution patterns:

- Airspace
- Unilateral or bilateral
- Lower lobes
- Subpleural, peribronchial
- Centrilobular (nodules and branching lines)
- Perilobular (less common) (airspace component of disease)

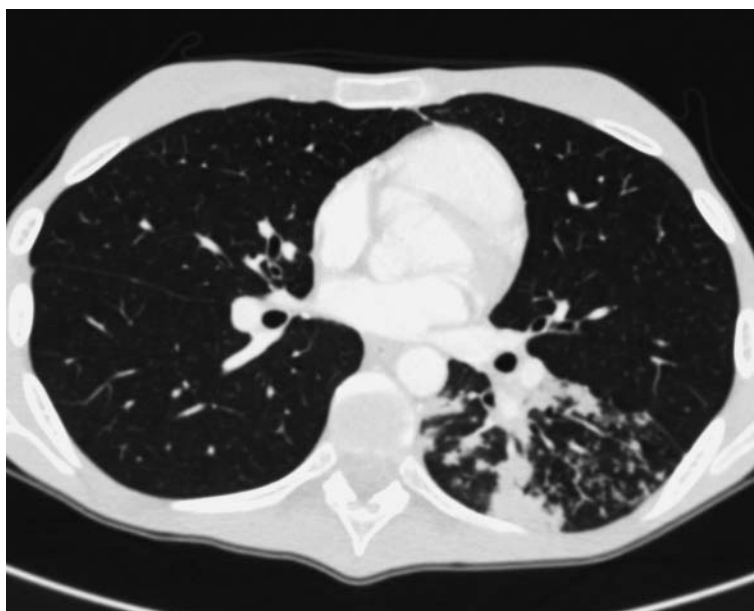
### Associated findings:

- Air bronchogram, sometimes with mild cylindrical bronchial dilatation
- Reticular opacities are less common but, when present, may be associated with histologic evidence of fibrosis
- Pleural effusion may occur

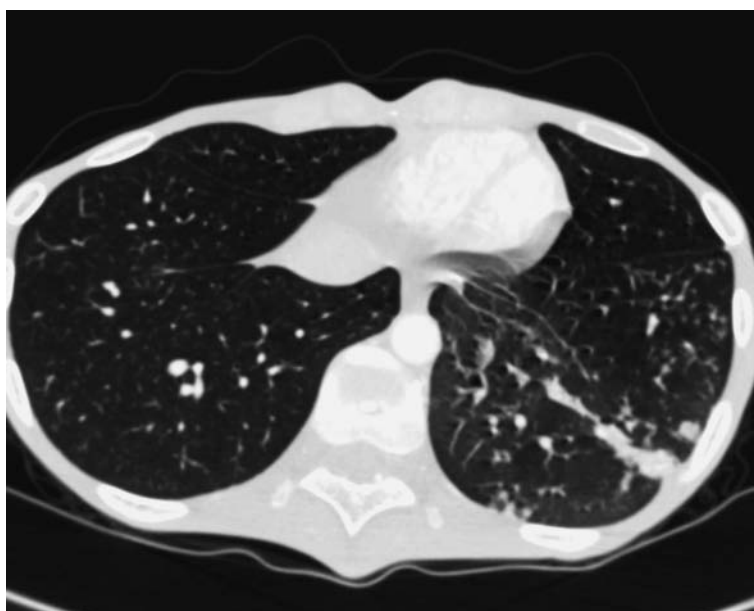
## References

- Lynch DA, Travis WD, Muller NL et al (2005) Idiopathic interstitial pneumonias: CT features. *Radiology* 236:10–21
- Polverosi R, Maffesanti M, Dalpiaz G (2006) Organizing pneumonia: typical and atypical HRCT patterns. *Radiol Med (Torino)* 111:202–212





7.1



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## Case 7

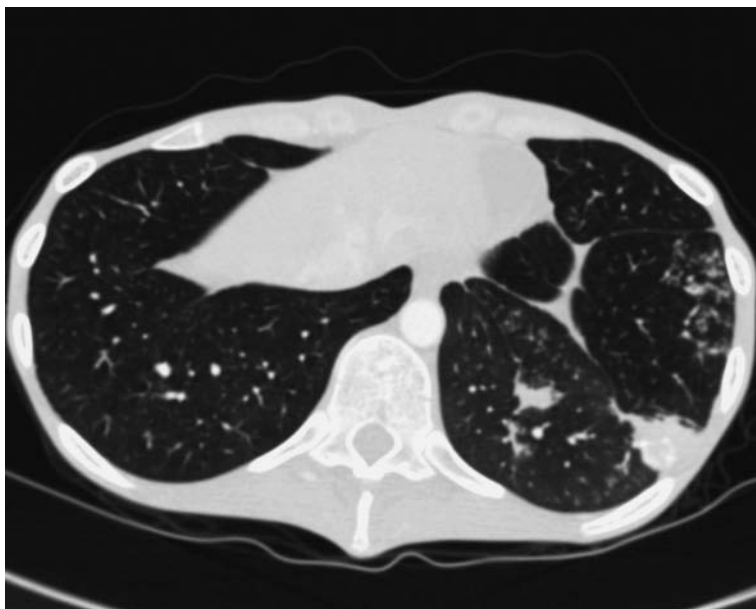
CT shows centrilobular opacities and areas of lung consolidation in the left lower lobe. The centrilobular opacities include small and large nodules, rosettes of nodules, branching lines and tree-in-bud.

## Diagnosis

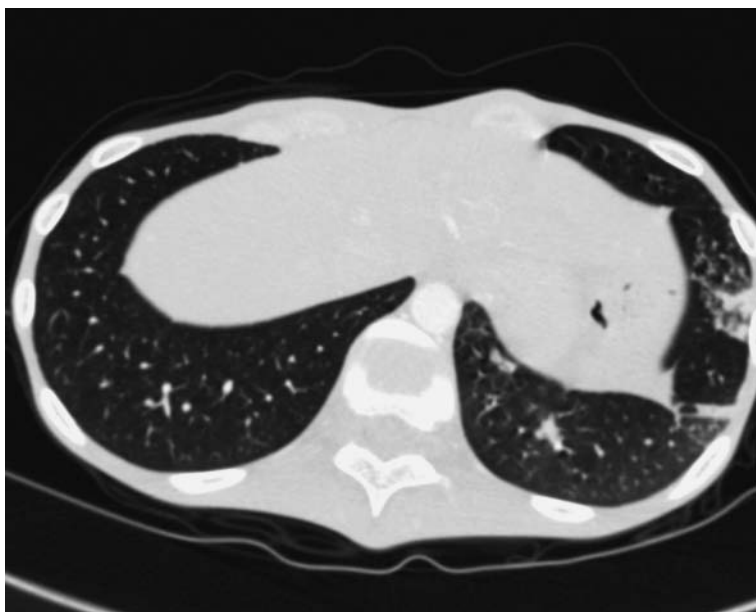
### Infectious bronchiolitis and bronchopneumonia

The term “bronchiolitis” refers to a broad morphologic spectrum of inflammatory events that are

centred on small conducting airways. Bronchiolitis may be an isolated pathologic finding, although it is often a secondary consequence of diseases affecting other parts of the lung. Bronchiolitis can be characterised by a cellular inflammation in the wall of the bronchioles with filling of the lumen with mucus and exudates (acute bronchiolitis, cellular bronchiolitis, exudative bronchiolitis, infectious bronchiolitis) or can be characterised by submucosal collagenisation (fibrosis) with chronic narrowing (constrictive bronchiolitis, bronchiolitis obliterans, obliterative bronchiolitis). The term “in-



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fectious bronchiolitis” refers to the fact that infection is the most frequent cause of the cellular or acute bronchiolitis, although other stimuli such as aspiration, toxic fume and gasses, drugs, cigarette smoking or diseases such as cystic fibrosis, chronic bronchitis and certain collagen vascular diseases can also cause acute or subacute inflammation of the bronchiolar wall.

## CT Findings

### Appearance patterns:

#### **Bronchiolitis**

- Nodular and linear:
  - Well-defined or ill-defined nodules, rosettes of nodules
  - Ground-glass or soft-tissue density (airspace nodules)
  - Centrilobular branching lines (V- or Y-shaped)
  - Tree-in-bud

#### **Bronchopneumonia**

- Increased attenuation:
  - Ground-glass
  - Consolidation
  - Crazy-paving

### Distribution patterns:

#### **Bronchiolitis**

- Airway, airspace
- Centrilobular
- Focal or diffuse, lobar

#### **Bronchopneumonia**

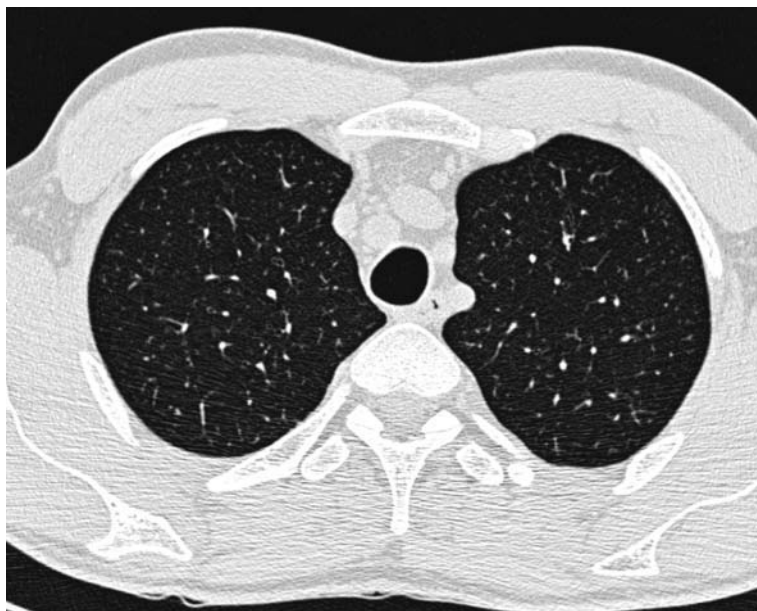
- Airspace
- Focal or diffuse, lobar

### Associated findings:

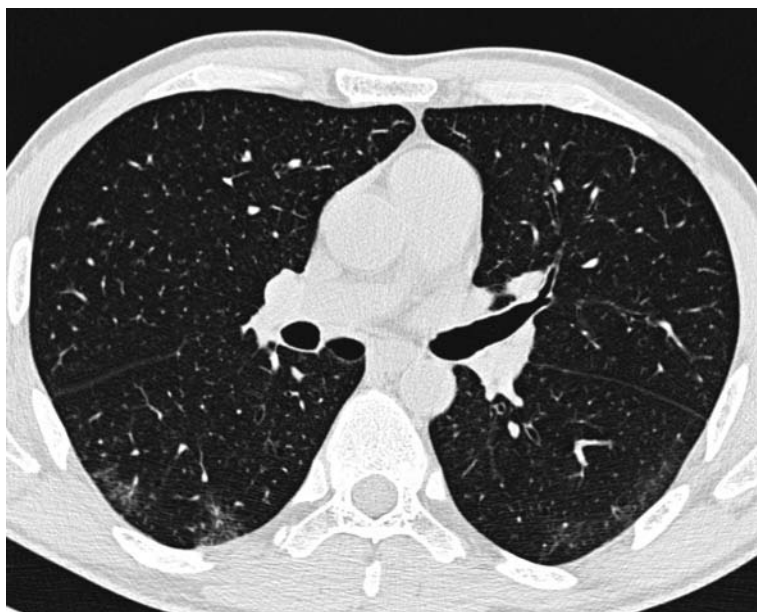
- Bronchial wall thickening, bronchiectasis, bronchiolectasis
- Mosaic attenuation on inspiratory CT (chronic disease)
- Air trapping on expiratory CT (chronic disease)

## References

- Pipavath SJ, Lynch DA, Cool C et al (2005) Radiologic and pathologic features of bronchiolitis. *AJR Am J Roentgenol* 185:354–363
- Verschakelen JA (2003) Imaging of the small airways. *Semin Respir Crit Care Med* 24:473–487
- Visscher DW, Myers JL (2006) Bronchiolitis: the pathologist’s perspective. *Proc Am Thorac Soc* 3:41–47



8.1



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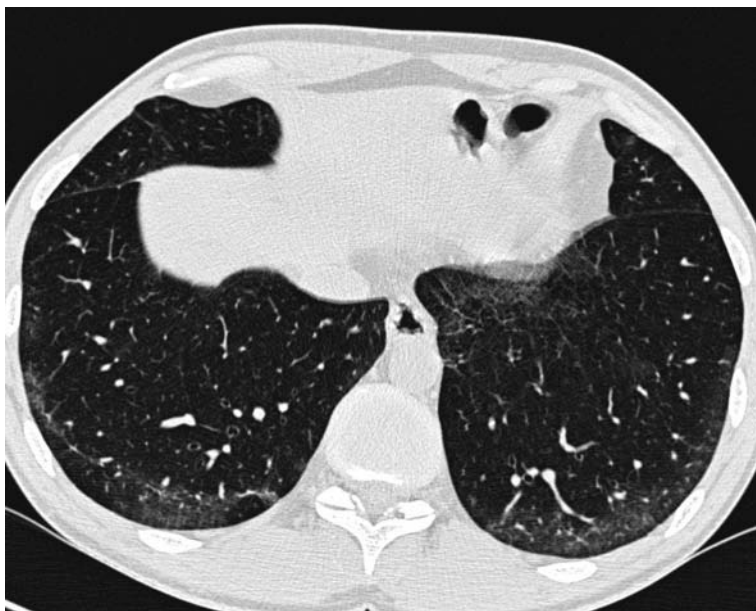
**Case 8**

Areas of increased lung attenuation (ground-glass attenuation) are seen in the posterior and basal parts of both lungs. Some associated linear opacities can be recognised within these ground-glass opacities.

**Diagnosis****Dermatomyositis (usual interstitial pneumonia)**

Polymyositis (PM) and dermatomyositis (DM) are systemic inflammatory diseases of unknown aetiology that affect skeletal muscles and other internal

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organs. Pulmonary involvement in PM/DM includes respiratory muscle weakness, aspiration pneumonia, interstitial lung disease (usually with a histological pattern of usual interstitial pneumonia [UIP], sometimes with a histological pattern of nonspecific interstitial pneumonia [NSIP]) or infection.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (may indicate active disease when not associated with signs of fibrosis)
  - Crazy-paving (may indicate active disease when not associated with signs of fibrosis)
  - Consolidation
- Linear:
  - Septal lines, intralobular reticular pattern, peribronchovascular interstitial thickening, subpleural interstitial thickening
  - Early: smooth
- Decreased attenuation:
  - Advanced: irregular
  - Honeycombing

### Distribution patterns:

- Interstitium (airspace)
- Bilateral patchy, dorsal subpleural, basal

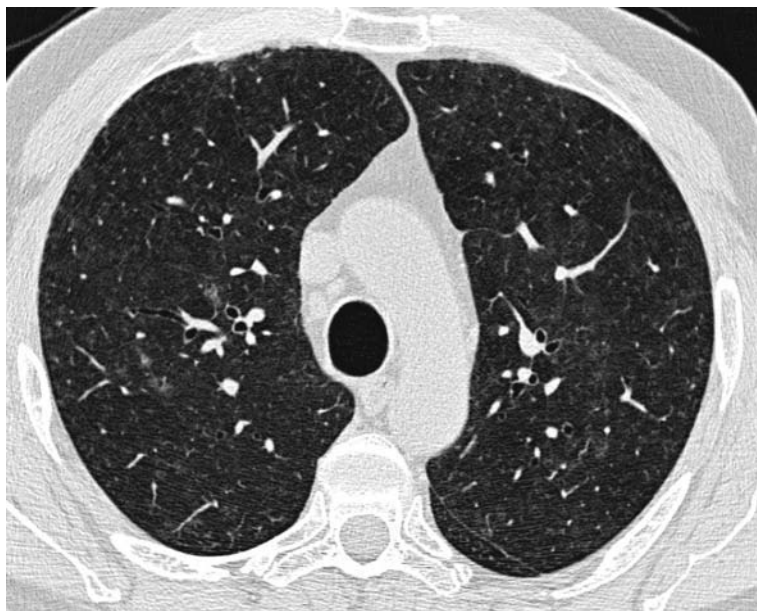
### Associated findings:

- Traction bronchiectasis, bronchiolectasis
- Enlarged mediastinal lymph nodes
- Signs of pulmonary arterial hypertension

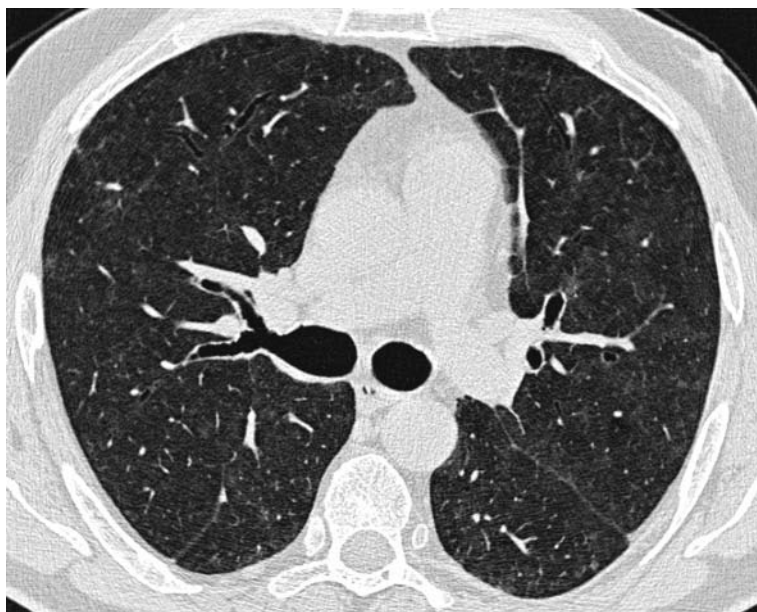
## References

- Kang EH, Lee EB, Shin KC et al (2005) Interstitial lung disease in patients with polymyositis, dermatomyositis and amyopathic dermatomyositis. *Rheumatology* 44:1282–1286
- Miller FW (2004) Polymyositis and dermatomyositis. In: Goldman L, Ausiello D (eds) *Cecil textbook of medicine*, 22<sup>nd</sup> edn. Saunders, Philadelphia, pp 1680–1684





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**Case 9**

Diffuse poorly circumscribed, ground-glass opacities that predominantly involve the central areas of the secondary pulmonary lobule. Abnormal high-density increase in the lung parenchyma together with air trapping limited to one or a few adjacent secondary pulmonary lobules is seen on the expiratory scans (9.3 and 9.4).

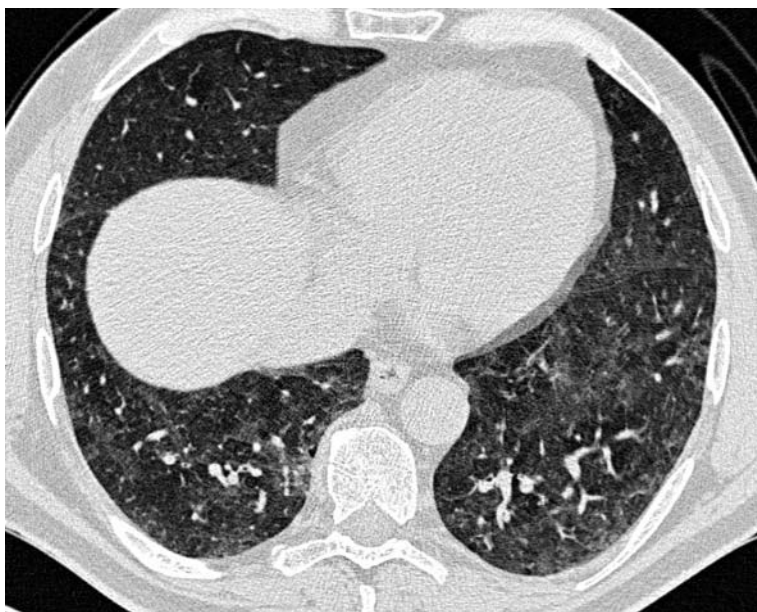
**Diagnosis****Subacute hypersensitivity pneumonitis  
(bird breeders' lung)**

Hypersensitivity pneumonitis, also known as extrinsic allergic alveolitis, is an allergic lung disease

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caused by the inhalation of antigens contained in a variety of organic dusts. Histologic abnormalities are alveolar interstitial thickening by mononuclear infiltrate, bronchiolitis (small bronchioles down to the proximal respiratory bronchioles) and small granulomas in the peribronchiolar interstitium. Proteinaceous exudates may be present.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
- Nodular:
  - Usually ill-defined nodules
  - Ground-glass density, sometimes soft-tissue density
- Decreased attenuation:
  - Air trapping
  - Mosaic perfusion
- Linear (less frequent):
  - centrilobular branching lines

### Distribution patterns:

- Airways (peribronchiolar), air-space
- Patchy, diffuse (ground-glass), upper lobes can be more involved
- Centrilobular (nodules and ground-glass)

### Associated findings:

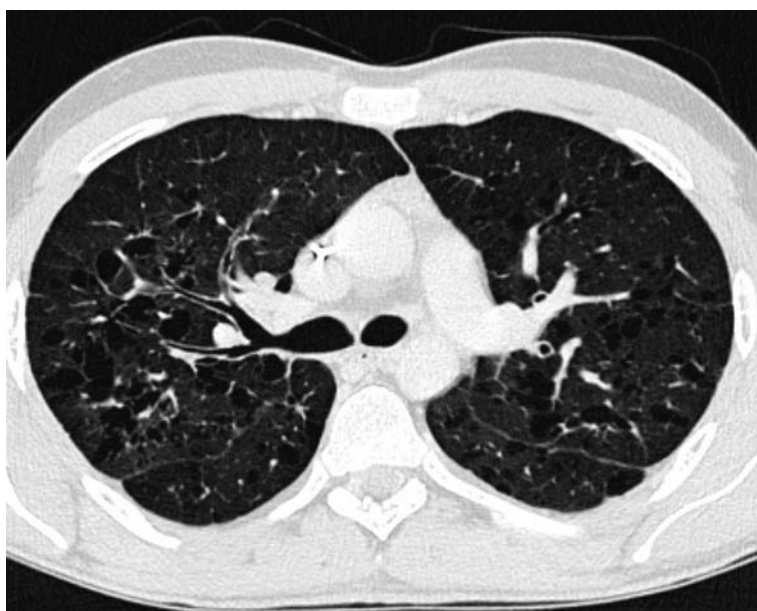
- Intralobular reticular pattern, irregular interlobular septal thickening, traction bronchiectasis and honeycombing when progressing to chronic stage

## References

- Hansell DM, Wells AU, Padley SP et al (1996) Hypersensitivity pneumonitis: correlation of individual CT patterns with functional abnormalities. *Radiology* 199:123–128
- Hartman TE (2003) The HRCT features of extrinsic allergic alveolitis. *Semin Respir Crit Care Med* 24:419–426



10.1



10.2

**Case 10**

Bilateral cystic lung changes predominantly involving the upper lobes. These cysts have a different size, are thin-walled and have a bizarre shape. There is upper lobe predominance and the costophrenic angles are spared.

**Diagnosis****Pulmonary Langerhans cell histiocytosis (cystic stage)**

Pulmonary Langerhans cell histiocytosis is an uncommon abnormality predominantly seen in young adult cigarette smokers. The earliest histologic finding is a cellular infiltrate predominantly existing of Langerhans cells in the interstitial tissue of the terminal and proximal respiratory bronchiolar walls.





### CT Findings

#### Appearance patterns:

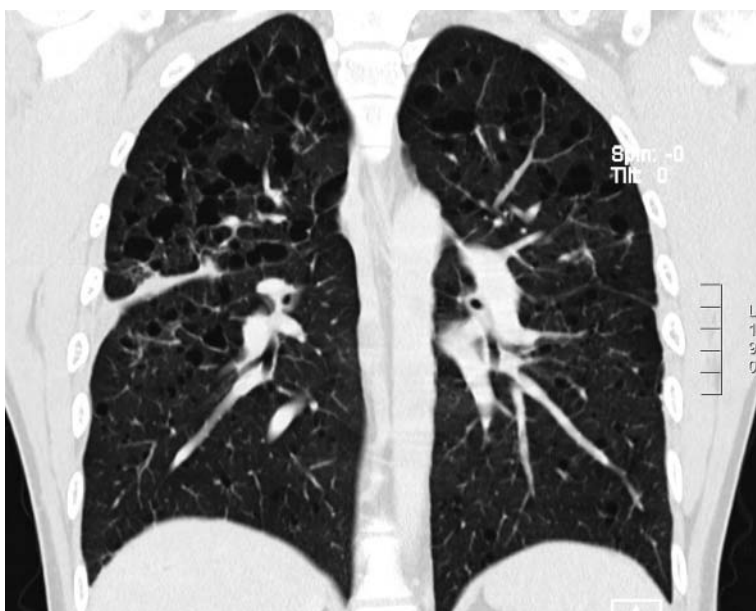
- Nodular (dominant finding in early disease):
  - Small, well-defined, usually <1–5 mm
  - Soft-tissue density (interstitial nodules)
- Decreased attenuation (dominant finding in advanced disease):
  - Cysts:
    - Round, bizarre-shaped (bilobed, clover-leaf-shaped, or branching)
  - Honeycombing and fibrosis: when further progression of disease

#### Distribution patterns:

- Peribronchiolar
- Nodules: centrilobular
- Upper lung zones with sparing of the costophrenic angles

#### Associated findings:

- Bronchial wall thickening

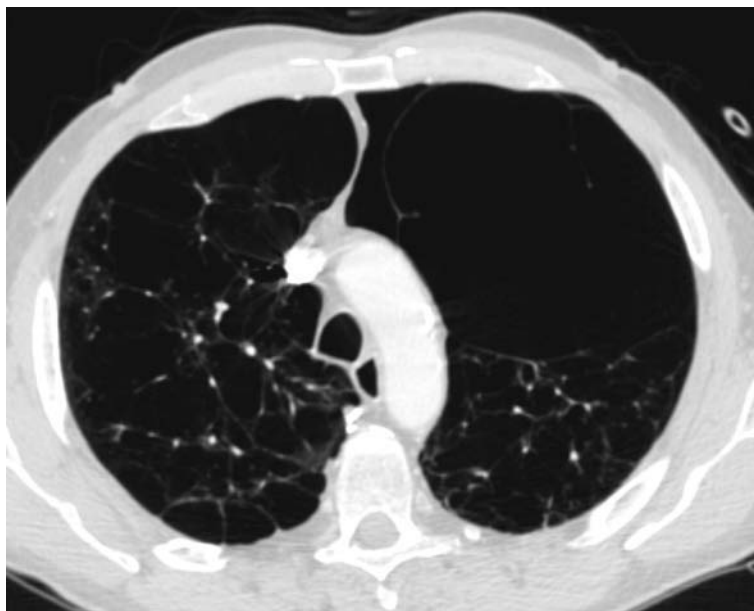


In more advanced disease, these infiltrates typically extend into alveolar interstitium surrounding the affected bronchioles and fibrosis occurs. With further progression of disease, coalescence of lesions and an increase in fibrosis can destroy the lung. Also, cystic lesions several millimetres to several centimetres in diameter are commonly seen. Their pathogenesis is uncertain but they may be the result of peripheral airspace dilatation secondary to bronchiolar obstruction or of necrosis of the central portion of the cellular nodules.

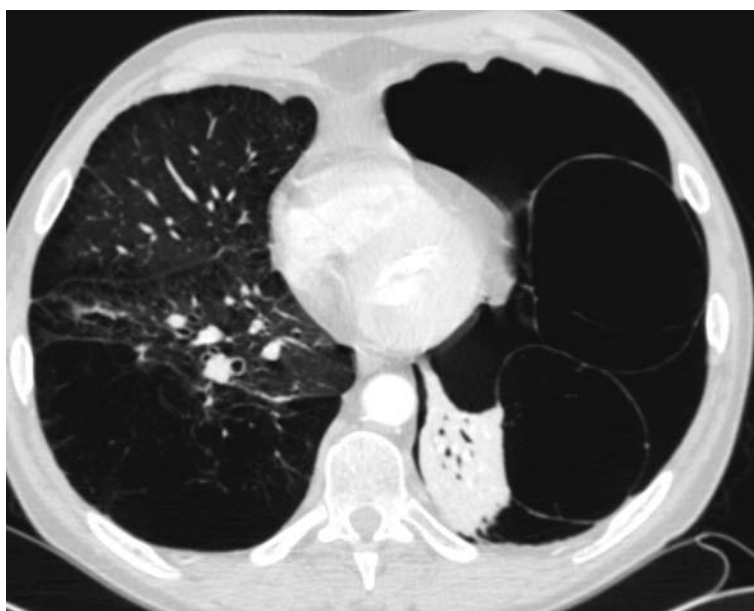
### Reference

Hidalgo A, Franquet T, Gimenez A et al (2006) Smoking-related interstitial lung diseases: radiologic-pathologic correlation. *Eur Radiol* 16:2463–2470





11.1



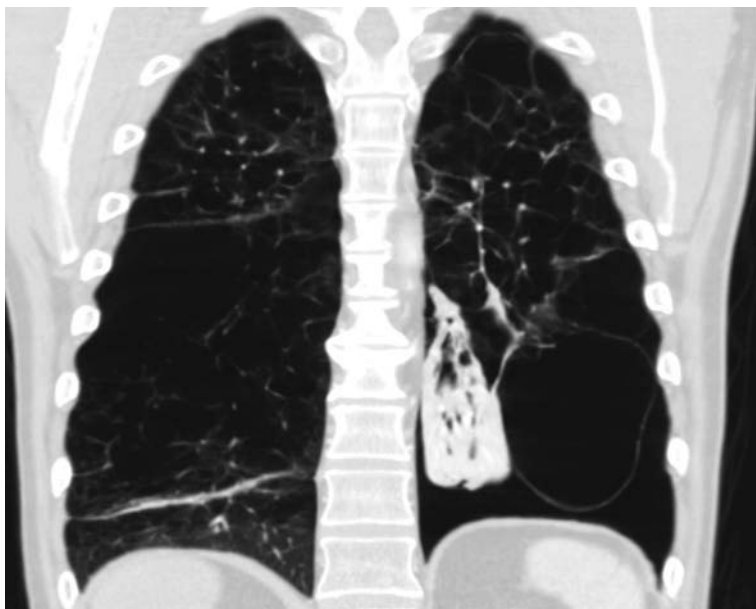
11.2

**Case 11**

Multiple large thin-walled, air-containing areas many of which have a diameter of more than 1 cm are seen in both lungs. Note also the left-sided pneumothorax.

**Diagnosis****Bullous emphysema**

Bullous emphysema is not a specific pathologic entity, but refers to the presence of emphysema associated with extensive areas of lung destruction. It is generally seen in patients with centrilobular emphysema and/or paraseptal emphysema.



### CT Findings

#### Appearance patterns:

- Decreased attenuation:
  - Extensive areas of lung destruction (one to several centimetres): bullae

#### Distribution patterns:

- Asymmetric
- Subpleural, upper lobes, may involve other lung areas

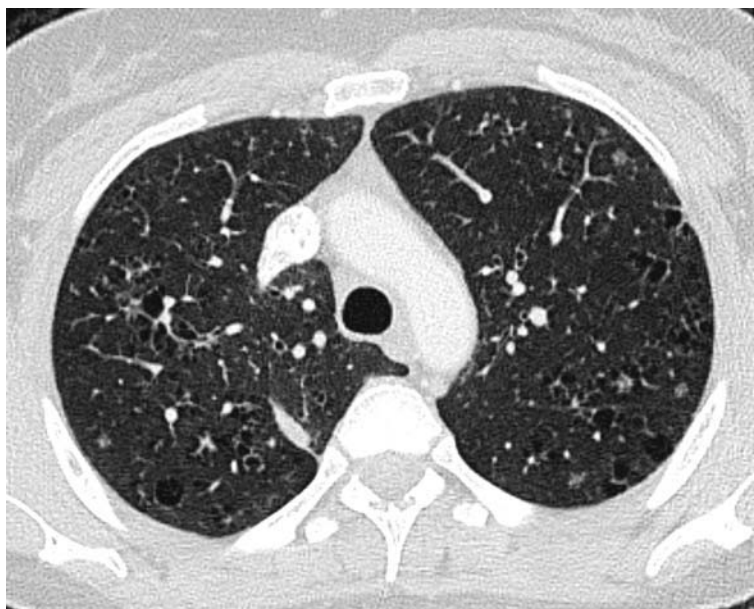
#### Associated findings:

- Paraseptal and centrilobular emphysema

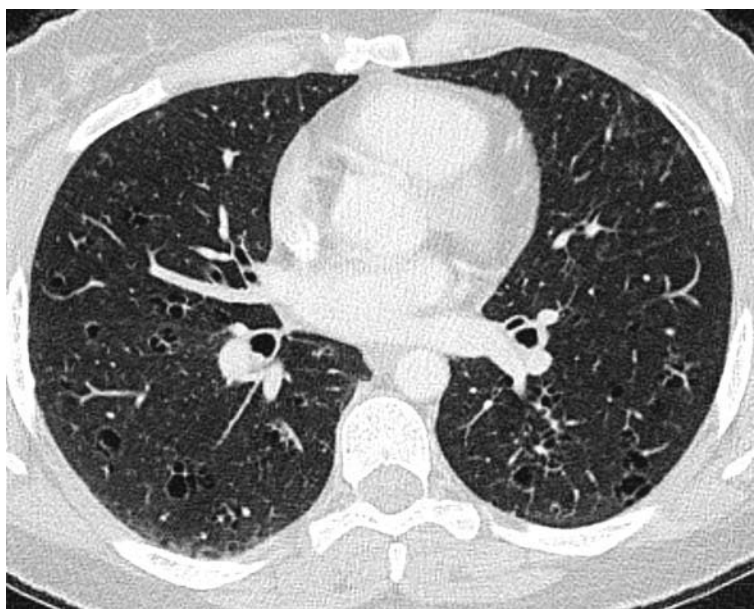


### Reference

Stern EJ, Webb WR, Weinacker A et al (1994) Idiopathic giant bullous emphysema (vanishing lung syndrome): imaging findings in nine patients. *AJR Am J Roentgenol* 162:279–282



12.1



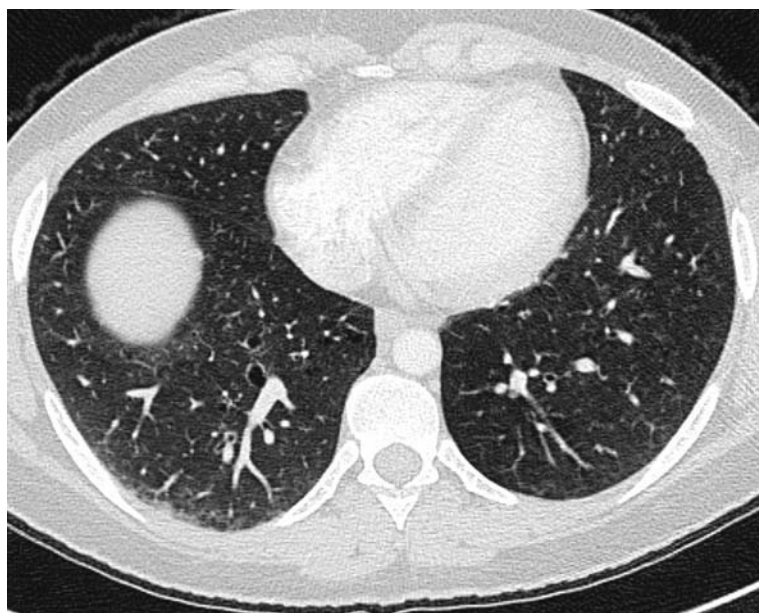
12.2

**Case 12**

Bilateral, small round and thin-walled cystic lung lesions and a few small centrilobular nodules best seen in the left upper lobe. Costophrenic angles are spared.

**Diagnosis****Pulmonary Langerhans cell histiocytosis (nodular and cystic stage)**

Pulmonary Langerhans cell histiocytosis is an uncommon abnormality predominantly seen in young adult cigarette smokers. The earliest histologic finding is a cellular infiltrate predominantly existing of Langerhans cells in the interstitial tissue of the terminal and proximal respiratory bronchiolar walls.



### CT Findings

#### Appearance patterns:

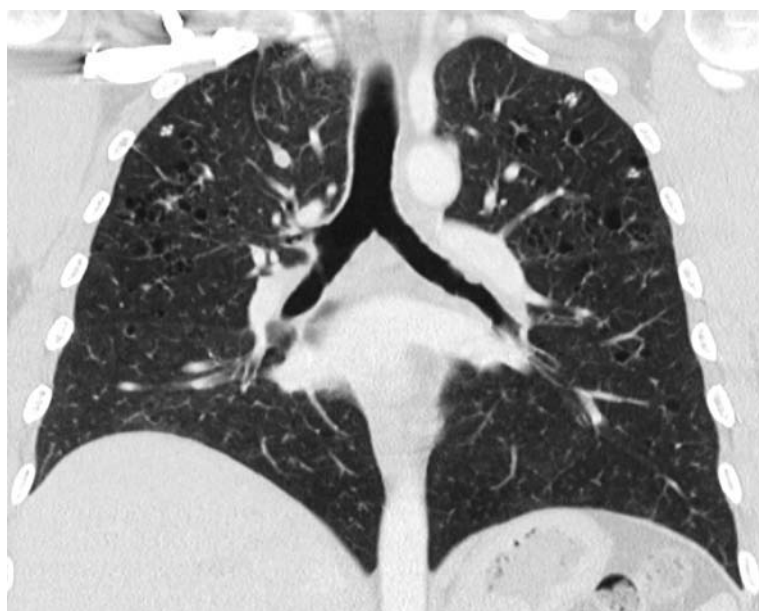
- Nodular (dominant finding in early disease):
  - Small, well-defined, usually <1–5 mm
  - Soft-tissue density (interstitial nodules)
- Decreased attenuation:
  - Cysts:
    - Round, bizarre-shaped (bilobed, clover-leaf-shaped, or branching)
    - Dominant finding in advanced disease
  - Honeycombing and fibrosis: when further progression of disease

#### Distribution patterns:

- Peribronchiolar
- Nodules: centrilobular
- Upper lung zones with sparing of the costophrenic angles

#### Associated findings:

- Bronchial wall thickening

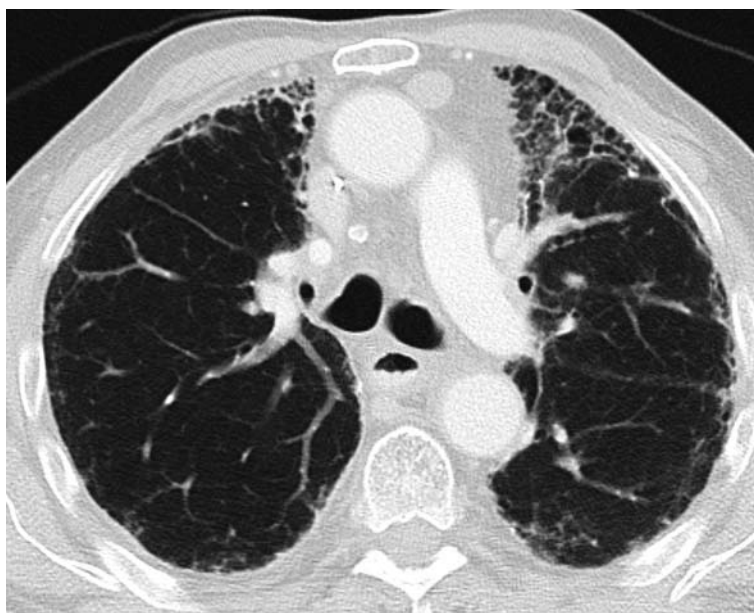


In more advanced disease, these infiltrates typically extend into the alveolar interstitium surrounding the affected bronchioles and fibrosis occurs. With further progression of disease, coalescence of lesions and an increase in fibrosis can destroy the lung. Also cystic lesions, several millimetres to several centimetres in diameter, are commonly seen. Their pathogenesis is uncertain but they may be the result of peripheral airspace dilatation secondary to bronchiolar obstruction or of necrosis of the central portion of the cellular nodules.

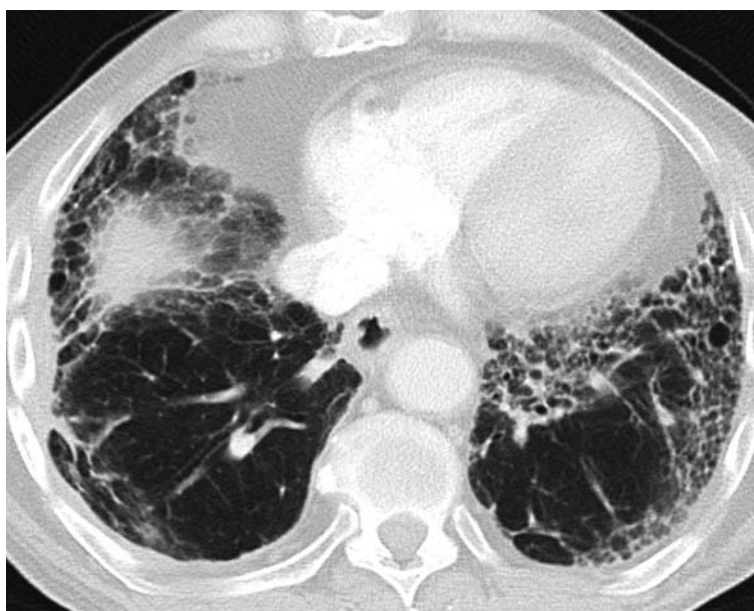
### Reference

Hidalgo A, Franquet T, Gimenez A et al (2006) Smoking-related interstitial lung diseases: radiologic-pathologic correlation. *Eur Radiol* 16:2463–2470





13.1



13.2

**Case 13**

Ground-glass opacity, linear opacities (intralobular reticular pattern), cystic lung changes and honeycombing are seen at the periphery of both lungs, predominantly in the lower lung regions. Also, larger linear opacities, lung deformation and bronchiectasis and bronchiolectasis can be observed.

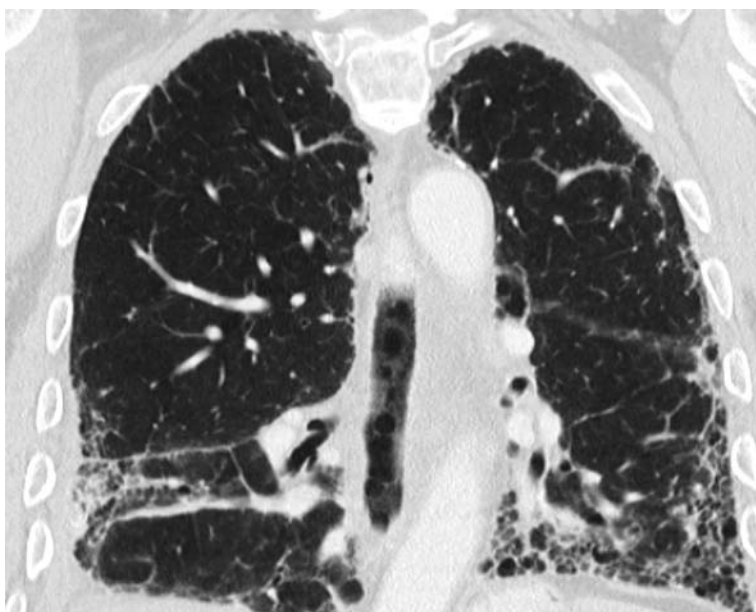
**Diagnosis****Idiopathic pulmonary fibrosis, usual interstitial pneumonia**

The terms “usual interstitial pneumonia” (UIP) and “idiopathic interstitial pneumonia” (IPF) have become much more narrowly defined since they were originally proposed several decades ago. The term “idiopathic pulmonary fibrosis” is now applied solely to the clinical syndrome associated

13.3



13.4



with the morphologic pattern of UIP and specifically excludes entities such as NSIP and desquamate interstitial pneumonia (DIP). IPF is the idiopathic form of UIP and corresponds histologically to a typical variability in appearance: foci of normal lung alternating with areas that show a variable degree of interstitial inflammation and fibrosis. The disease tends to be more prominent in the subpleural than in the central parenchyma, and is usually more severe in the basal region of the lower lobes.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (may indicate active disease when not associated with signs of fibrosis)
  - Crazy-paving (may indicate active disease when not associated with signs of fibrosis)
  - Consolidation
- Linear:
  - Septal lines, intralobular reticular pattern, peribronchovascular interstitial thickening, subpleural interstitial thickening
  - Early: smooth
  - Advanced: irregular
- Decreased attenuation:
  - Honeycombing

### Distribution patterns:

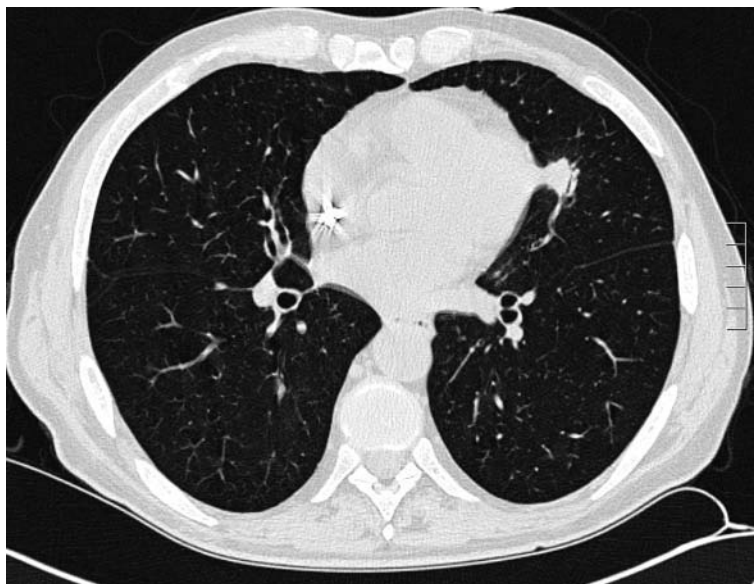
- Interstitium, airspace
- Bilateral patchy, dorsal subpleural, basal

### Associated findings:

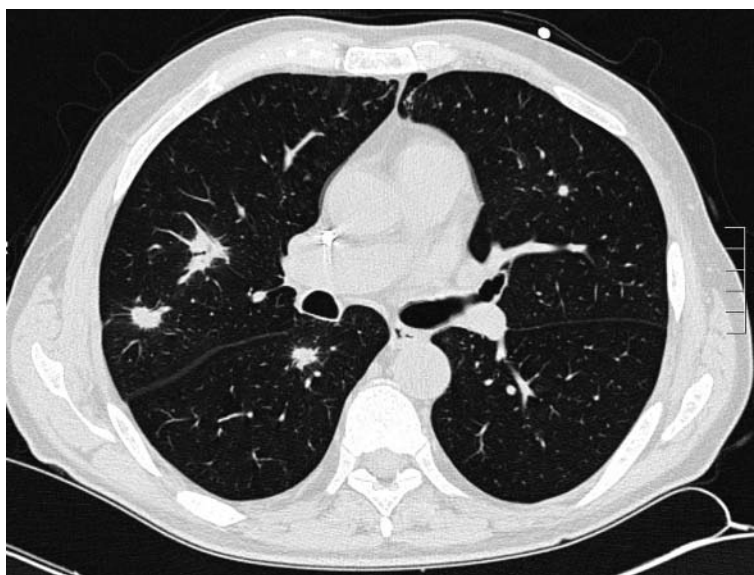
- Traction bronchiectasis, bronchiolectasis
- Mediastinal lymph nodes
- Signs of Pulmonary arterial hypertension

## Reference

Lynch DA, Travis WD, Muller NL et al (2005) Idiopathic interstitial pneumonias: CT features. *Radiology* 236:10–21



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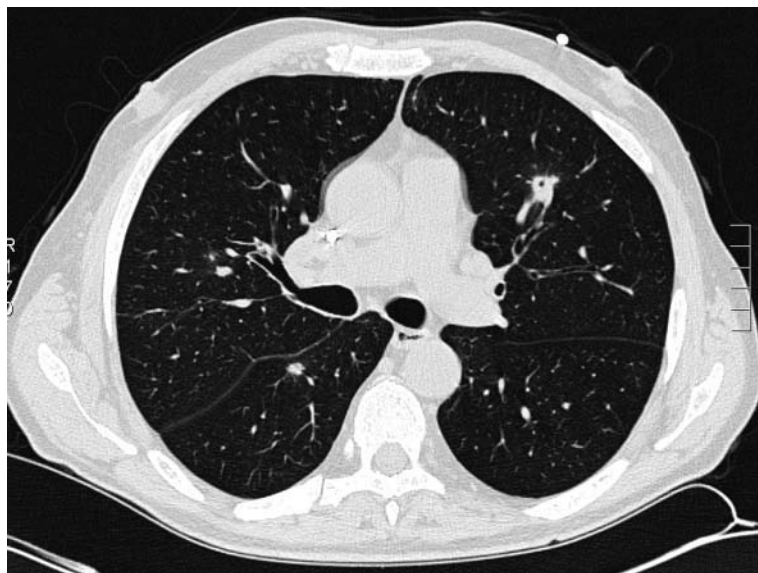
**Case 14**

CT shows several irregular and poorly defined small and large nodular opacities. Some of these are surrounded by a rim of ground-glass density (halo sign).

**Diagnosis****Angioinvasive pulmonary aspergillosis**

Invasive aspergillosis occurs when there is an extension of aspergillus into viable tissue and is almost exclusively seen in immunocompromised patients





### CT Findings

#### Appearance patterns:

- Nodules:
  - Small, large, conglomerating, ill-defined and well-defined nodules
  - Soft-tissue density
- Increased attenuation:
  - Ground-glass rim surrounding nodules (halo-sign)
- Decreased attenuation:
  - Cavitary nodules (air crescent sign)

#### Distribution patterns:

- Airspace
- Patchy

#### Associated findings:

- Consolidation: pleura-based, wedge-shaped caused by pulmonary haemorrhage



with severe neutropenia. Angioinvasive pulmonary aspergillosis, together with the acute aspergillus bronchopneumonia, is the most common form of disease. This form of aspergillus infection is usually multifocal and nodular in appearance. A rim of haemorrhage and/or consolidated lung is frequently found surrounding the nodule.

### Reference

Franquet T, Muller NL, Gimenez A et al (2001) Spectrum of pulmonary aspergillosis: histologic, clinical, and radiologic findings. *Radiographics* 21:825–837





15.1



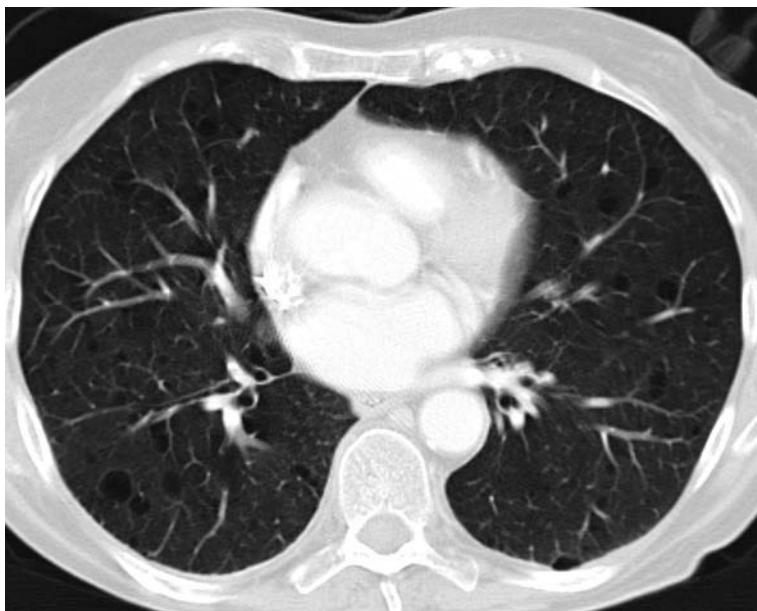
15.2

**Case 15**

CT shows multiple thin-walled cystic lesions diffusely distributed in both lungs.

**Diagnosis****Lymphangioleiomyomatosis**

Lymphangioleiomyomatosis (LAM) is a rare disease of uncertain aetiology characterised histologically by a proliferation of smooth muscle predominantly around small airways and vessels. In more advanced disease, cystic spaces whose pathogenesis is unclear



### CT Findings

#### Appearance patterns:

- Decreased attenuation:
  - Cysts:
    - Size: 2 mm–5 cm (large cysts indicate severe disease)
    - Thin-walled
    - Round

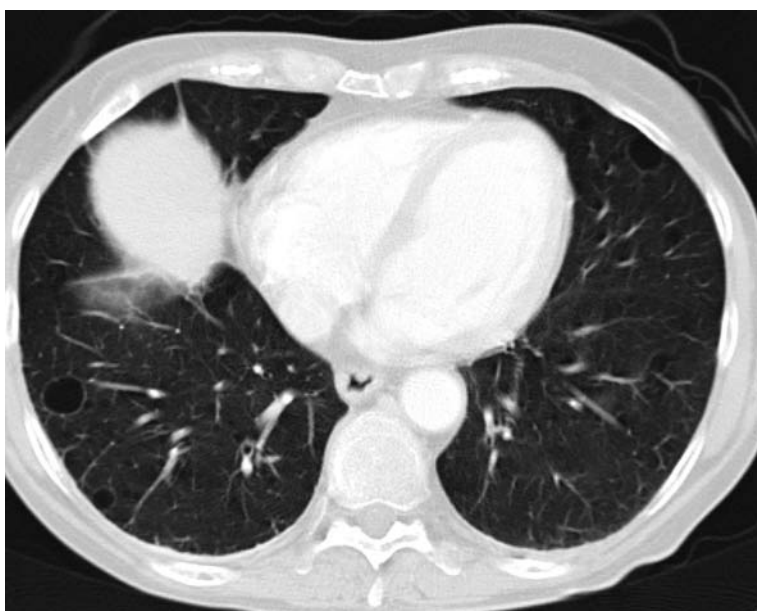
#### Distribution patterns:

- Peribronchiolar, centrilobular
- Diffuse, no lung zone is spared

#### Associated findings:

- Pneumothorax
- Pleural effusion (chylothorax)
- Ground-glass opacity (pulmonary haemorrhage)
- Small nodules (occasionally)

15.3

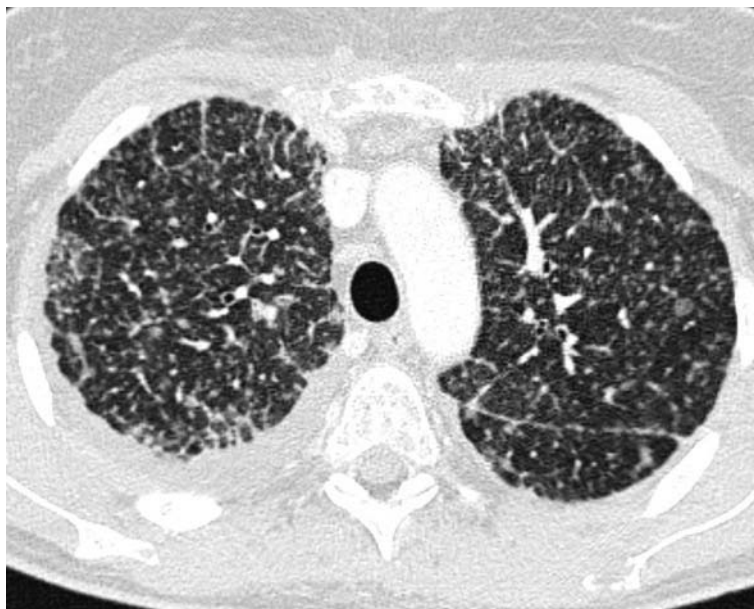


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are found, but this may be explained by the fact that obstruction of the small airways by the proliferating smooth muscle cells results in distal airway dilatation. LAM almost exclusively affects females, generally developing before menopause. The disease is characterised by progressive pulmonary cystic change, recurrent pneumothorax, chylous pleural collections and, in most cases, progressive respiratory failure.

### Reference

Johnson SR (2006) Lymphangioleiomyomatosis. *Eur Respir J* 27:1056–1065



16.1



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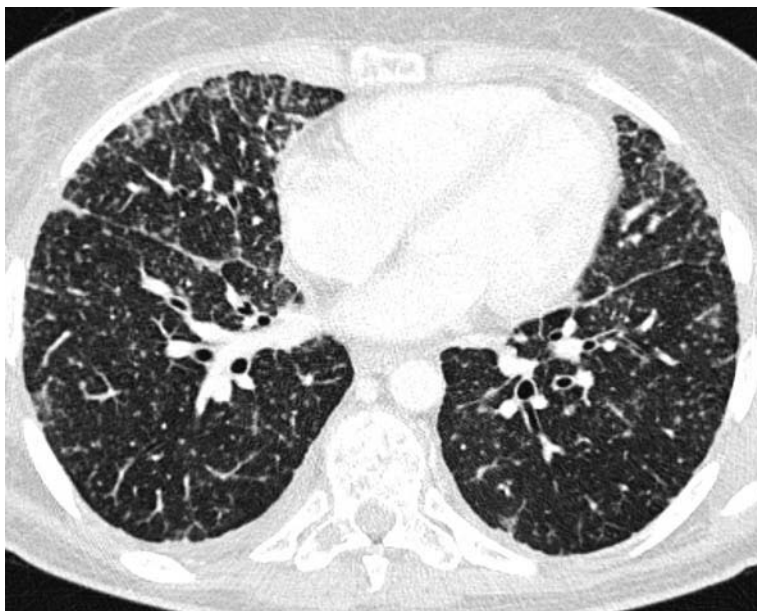
## Case 16

Multiple small, well-defined and dense nodules are seen in both lungs. These nodules are predominantly located in the subpleural interstitium (also along the great fissures) and in the interlobular septa (beaded septa). Some nodules are centrilobular, whereas some interlobular septa show a more homogenous thickening (linear opacities).

## Diagnosis

### Lymphangitic spread of tumour

“Lymphangitic spread of tumour” or “pulmonary lymphangitic carcinomatosis” (PLC) are terms that refer to tumour growth in the lymphatic system of the lungs. PLC usually results from haematogenous spread to the lung, with subsequent interstitial and lymphatic invasion, but can also occur because of direct lymphatic spread of tumour from mediastinal and hilar lymph nodes.



### CT Findings

#### Appearance patterns:

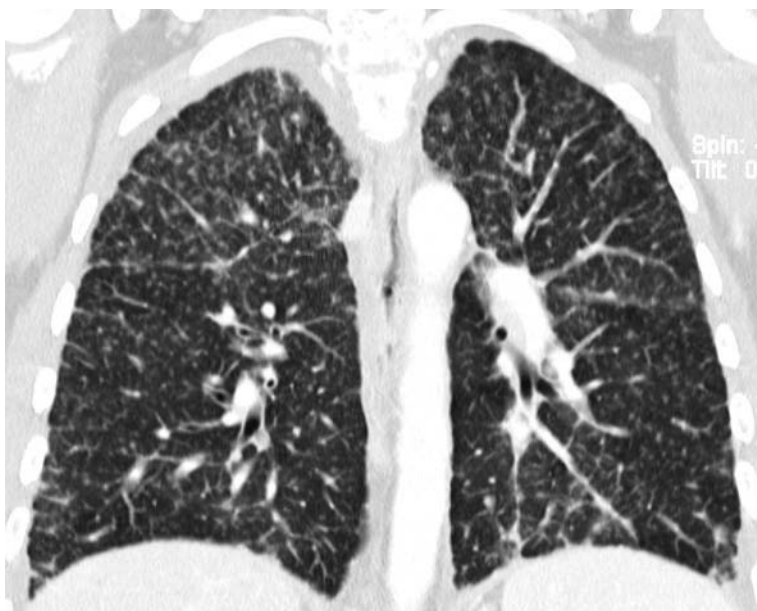
- Nodular:
  - Small, well-defined nodules
  - Soft-tissue density
- Linear:
  - Septal lines, intralobular branching lines, subpleural thickening, proximal peribronchovascular thickening
  - Combination with nodules: beaded septa

#### Distribution patterns:

- Lymphatic
- Diffuse, patchy, unilateral

#### Associated findings:

- Lymph node enlargement
- Pleural effusion
- Large nodules



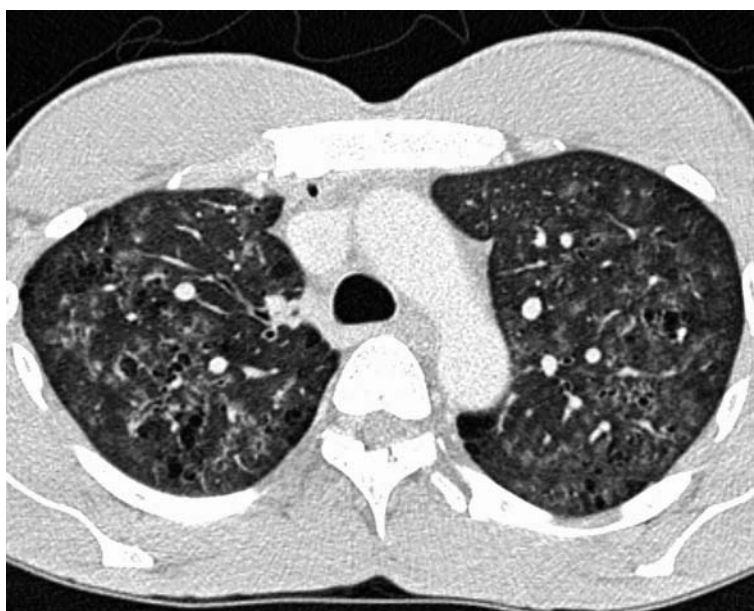
### References

- Davis SD (1991) CT evaluation for pulmonary metastases in patients with extrathoracic malignancy. *Radiology* 180:1–12
- Johkoh T, Ikezoe J, Tomiyama N et al (1992) CT findings in lymphangitic carcinomatosis of the lung: correlation with histologic findings and pulmonary function tests. *AJR Am J Roentgenol* 158:1217–1222





17.1



17.2

**Case 17**

Diffuse poorly circumscribed, ground-glass opacities that predominantly involve the central areas of the secondary pulmonary lobule. Small round areas of extreme low density corresponding with centrilobular emphysema are also seen.

**Diagnosis****Respiratory bronchiolitis interstitial lung disease**

Respiratory bronchiolitis interstitial lung disease (RB-ILD) is a clinicopathological entity seen almost exclusively in current or former cigarette smokers. RB-ILD has been defined as the clinical manifestation (cough, dyspnoea, combined restrictive and obstructive lung disease) of intersti-



### CT Findings

#### Appearance patterns:

- Nodular:
  - Small, ill-defined nodules
  - Ground-glass opacity (airspace nodules)
- Increased attenuation:
  - Ground-glass

#### Distribution patterns:

- Airway, airspace
- Ground-glass: more pronounced centrilobular
- Nodules: centrilobular
- Diffuse, patchy, upper lung

#### Associated findings:

- Centrilobular emphysema
- Mild signs of fibrosis
- Bronchial wall thickening
- Mosaic perfusion, air trapping



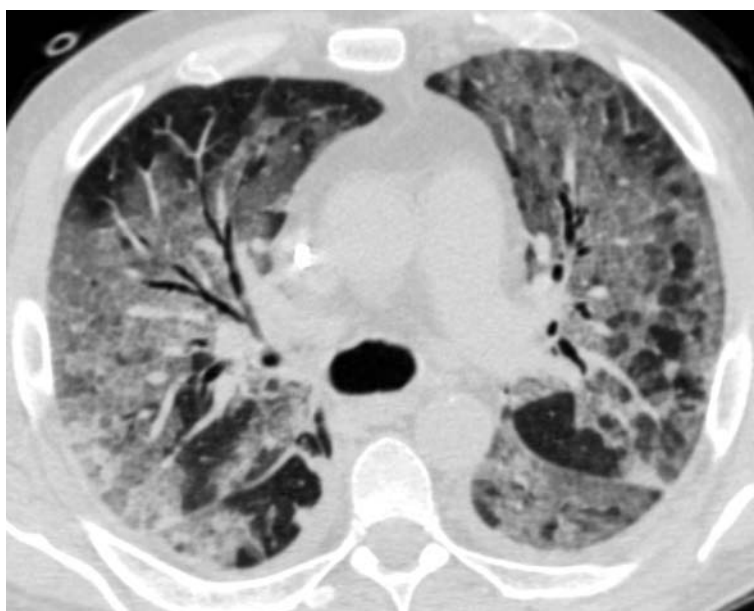
tial lung disease associated with the pathological lesion of respiratory bronchiolitis. It is characterised histologically by inflammation and mild fibrosis of the walls of the respiratory bronchioles accompanied by the accumulation of pigmented macrophages in their lumen and the lumen of adjacent alveoli. RB-ILD is thought to be on the spectrum of disease as desquamative interstitial lung disease (DIP), both of which are associated with cigarette smoking.

### References

- Caminati A, Harari S (2006) Smoking-related interstitial pneumonias and pulmonary Langerhans cell histiocytosis. *Proc Am Thorac Soc* 3:299–306
- Hansell DM, Nicholson DM (2003) Smoking-Related Diffuse Parenchymal Lung Disease: HRCT-Pathologic Correlation. *Seminars in Respiratory and Critical Care Medicine* 24:377–391



18.1



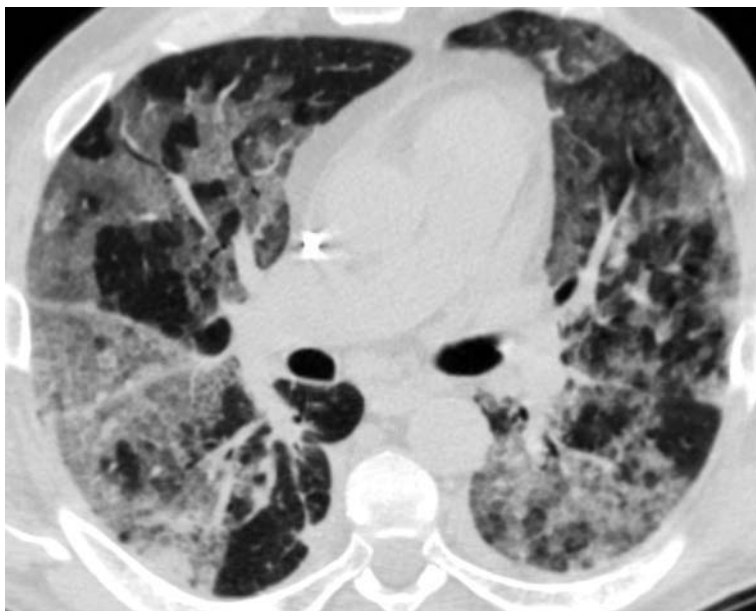
18.2

**Case 18**

Ground-glass and crazy-paving patterns together with limited consolidation are seen in both lungs, partially organised in a geographic distribution. There is no pleural effusion and the heart is normal.

**Diagnosis****Acute interstitial pneumonia**

Acute interstitial pneumonia (AIP) is a rapidly progressive form of interstitial pneumonia. The histologic findings are those of diffuse alveolar damage (DAD) indistinguishable from the histo-



### CT Findings

#### Appearance patterns:

- Increased attenuation:
  - Ground-glass (partial filling of airspaces)
  - Crazy-paving (partial filling of airspaces)
  - Consolidation (complete filling of airspaces)
- Linear:
  - Septal lines
  - Intralobular reticular pattern

#### Distribution patterns:

- Interstitium, airspace
- Early exudative phase: areas of ground-glass opacities, often bilateral and patchy, with lower-lobe predominance and with areas of focal lung sparing producing a geographic appearance
- Consolidation particularly in the dependent lung

#### Associated findings:

- Advanced disease: architectural distortion, traction bronchiectasis and honeycombing
- Residual findings: areas of hypoattenuation, lung cysts, reticular pattern, and associated parenchymal distortion occurring mainly in the nondependent lung



logic pattern found in adult (acute) respiratory distress syndrome (ARDS) caused by sepsis and shock. Oedema and hyaline membranes are prominent in the acute phase, and organising alveolar septal fibrosis and pneumocyte hyperplasia are conspicuous in the organising phase. The term “acute interstitial pneumonia” is reserved for diffuse alveolar damage of unknown origin.

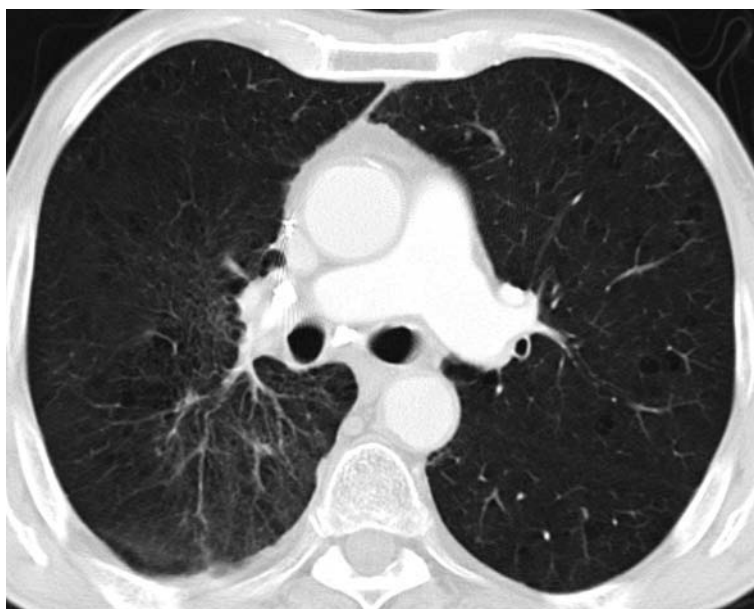
### Reference

Lynch DA, Travis WD, Muller NL et al (2005) Idiopathic interstitial pneumonias: CT features. *Radiology* 236:10–21





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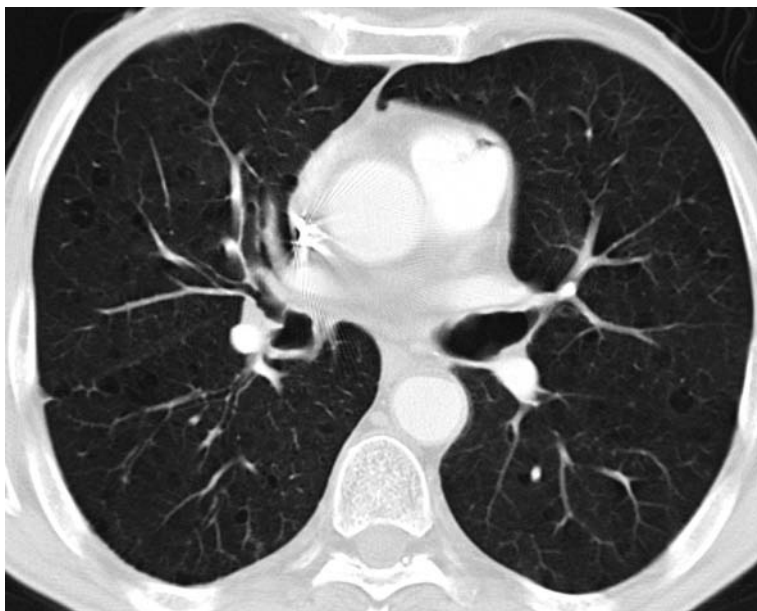
## Case 19

Multiple small rounded areas of extremely low lung density without a wall are seen in both lungs (predominantly in middle and upper lung). In some of these lesions, a small dot is seen at the centre corresponding to the centrilobular artery. At the most apical CT slice, these lesions become confluent and larger areas of very low density and lung destruction are created, around which thin walls can be recognised. On this slice subpleural low-density areas can also be seen.

## Diagnosis

**Mild centrilobular emphysema, confluent centrilobular emphysema and paraseptal emphysema**

Emphysema is defined as a permanent, abnormal enlargement of airspaces distal to the terminal bronchiole, accompanied by the destruction of the walls of the involved airspaces. In centrilobular emphysema, the airspaces surrounding the centrilobular bronchovascular bundle are predominantly involved.



### CT Findings

#### Appearance patterns:

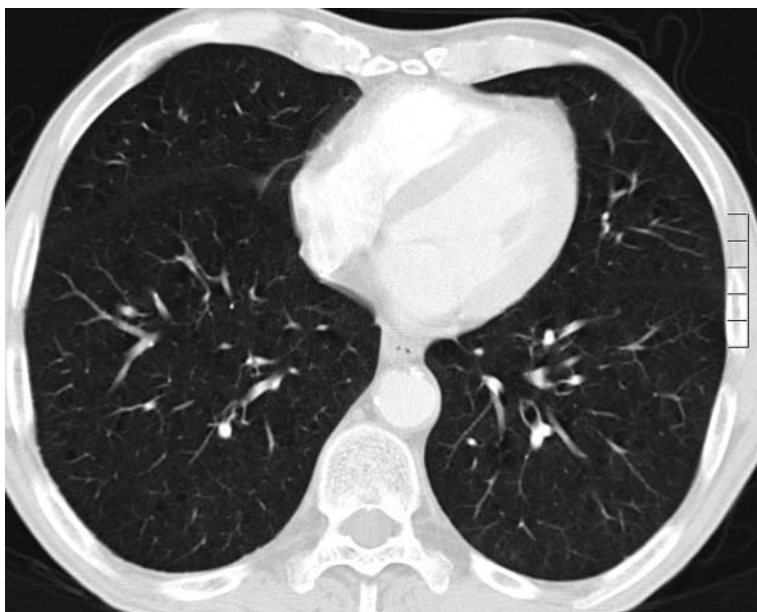
- Decreased attenuation:
  - Rounded, centrilobular, small lucencies, without a wall, often with a central dot corresponding to the centrilobular artery
  - Confluent lucencies often with a recognisable wall and associated with lung destruction

#### Distribution patterns:

- Centrilobular
- Patchy
- Upper lobe predominance

#### Associated findings:

- Paraseptal emphysema
- Bullous emphysema

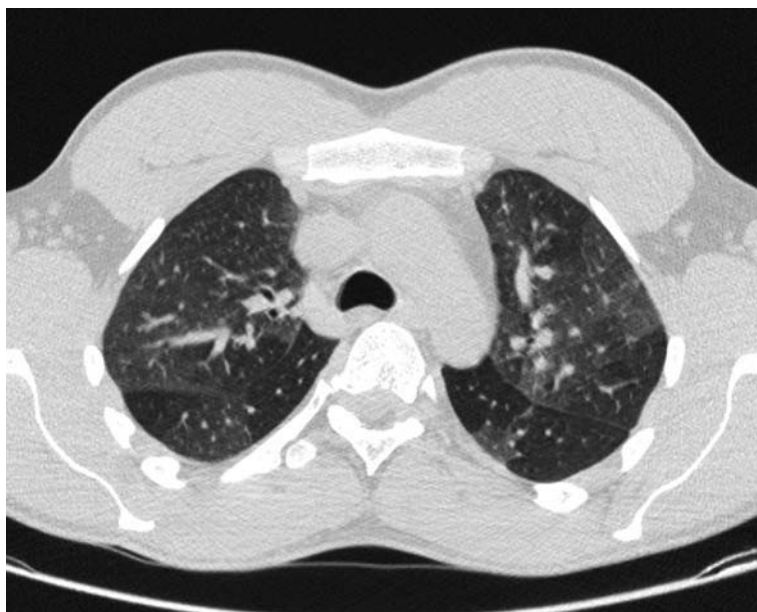


### Reference

Naidich DP (1991) High-resolution computed tomography of cystic lung disease. *Semin Roentgenol* 26:151–174



20.1



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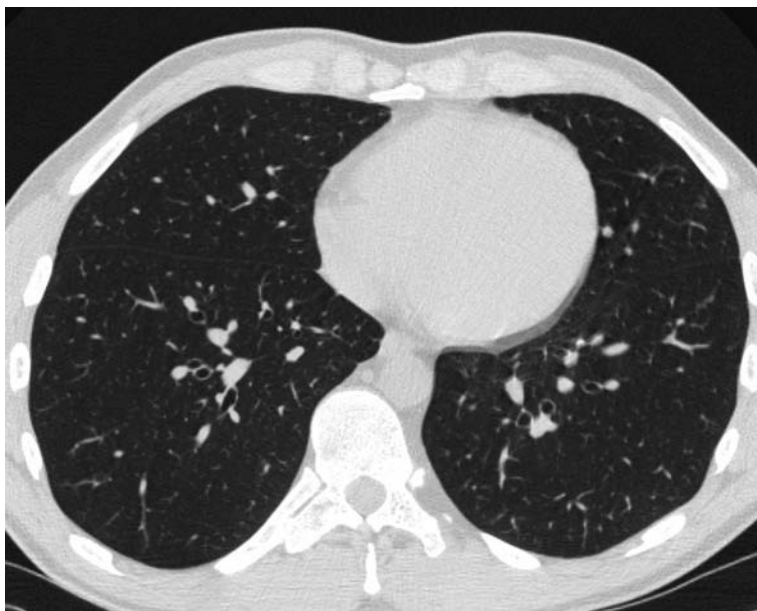
## Case 20

On the expiratory scans (20.2, 20.4), multiple areas of air-trapping are seen, which are barely visible on the inspiratory scans (20.1, 20.3). They can, however, be recognised because of a slight decrease in vascular markings and lung density.

## Diagnosis

### Bronchiolitis obliterans with air trapping

The term “bronchiolitis” refers to a broad morphologic spectrum of inflammatory events that are centred on small conducting airways. Bronchiolitis may be an isolated pathologic finding, although it is often a secondary consequence of diseases affecting other parts of the lung. Bronchiolitis can be characterised by a cellular inflammation in the wall of the bronchioles with filling of the lumen with mucus and



20.3



20.4

## CT Findings

### Appearance patterns:

- Decreased attenuation:
  - Air trapping
  - Mosaic perfusion

### Distribution patterns:

- Airway
- Often patchy but can be diffuse or focal

### Associated findings:

- Bronchial wall thickening
- Rarely centrilobular opacities

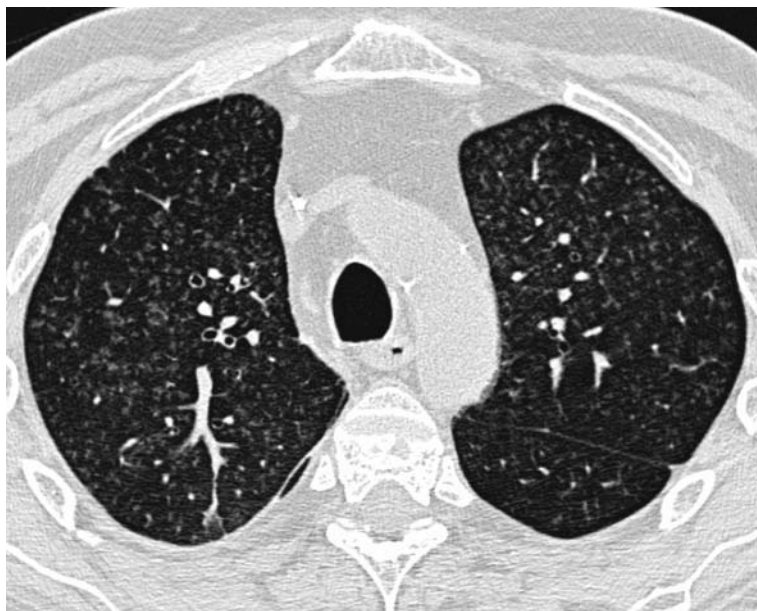
exudates (acute bronchiolitis, cellular bronchiolitis, exudative bronchiolitis, infectious bronchiolitis) or can be characterised by submucosal collagenisation (fibrosis) with chronic narrowing (constrictive bronchiolitis, bronchiolitis obliterans, obliterative bronchiolitis).

Bronchiolitis obliterans is associated with organ transplantation, healed infections (viral, mycoplasma), connective tissue diseases, inhalation injury, certain drugs, chronic bronchitis, cystic fibrosis and bronchiectasis and may also have an idiopathic origin.

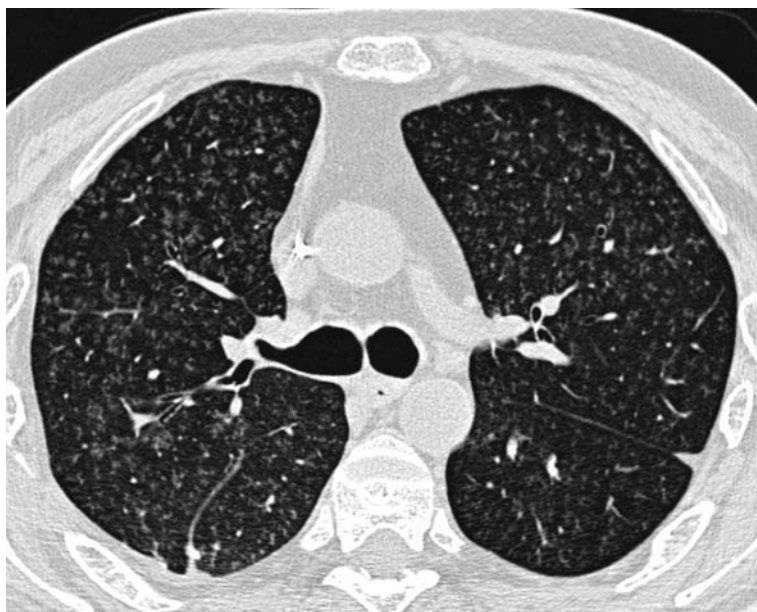
## References

- Angel L, Homma A, Levine SM (2000) Bronchiolitis obliterans. *Semin Respir Crit Care Med* 21:123–134
- Jensen SP, Lynch DA, Brown KK et al (2002) High-resolution CT features of severe asthma and bronchiolitis obliterans. *Clin Radiol* 57:1078–1085





21.1



21.2

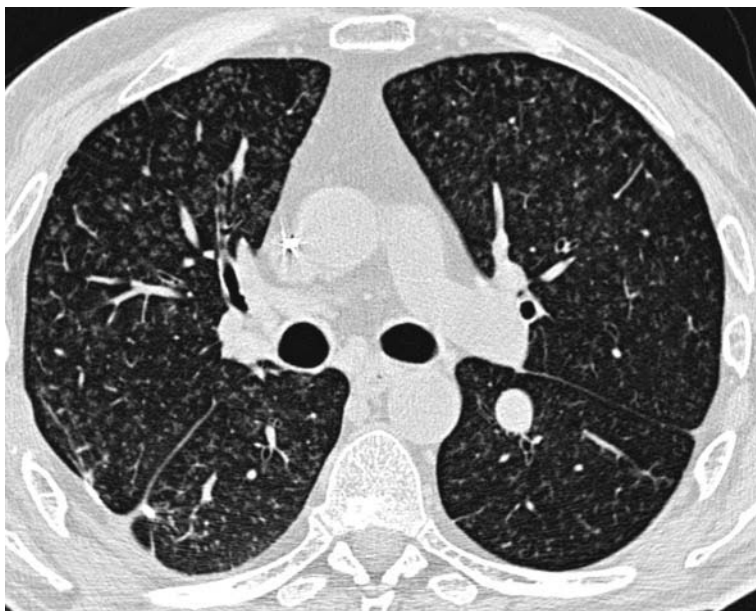
**Case 21**

Diffuse nodular pattern affecting both lungs. The nodules are dense and have a centrilobular distribution.

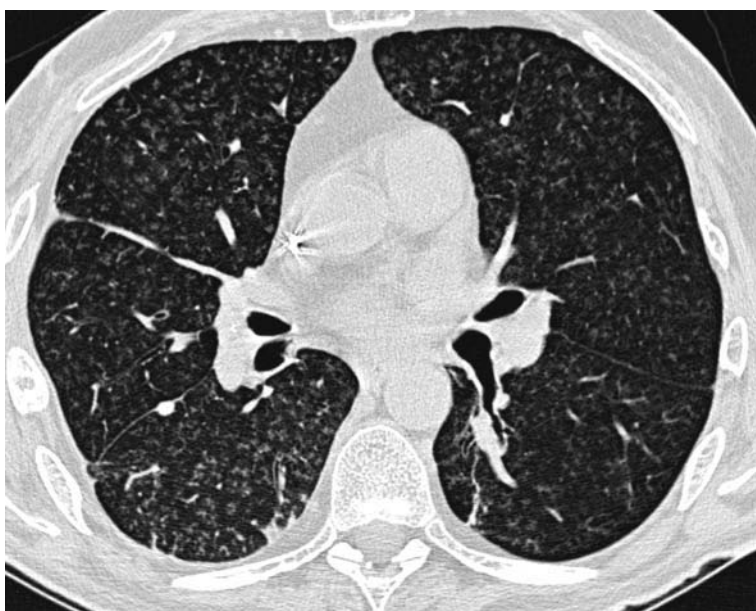
**Diagnosis****(Subacute) hypersensitivity pneumonitis**

Hypersensitivity pneumonitis, also known as extrinsic allergic alveolitis, is an allergic lung disease caused by the inhalation of antigens contained in a variety of organic dusts. Histologic abnormalities are alveolar interstitial thickening by mononuclear infiltrate, bronchiolitis (small bronchioles down to the proximal respiratory bronchioles) and small granulomas in the peribronchiolar interstitium. Proteinaceous exudates may be present.

21.3



21.4



## CT Findings

### Appearance patterns:

- Nodular:
  - Usually ill-defined nodules
  - Ground-glass density, sometimes soft tissue density
- Increased attenuation:
  - Ground-glass
- Decreased attenuation:
  - Air trapping
  - Mosaic perfusion
- Linear (less frequent)
  - centrilobular branching lines

### Distribution patterns:

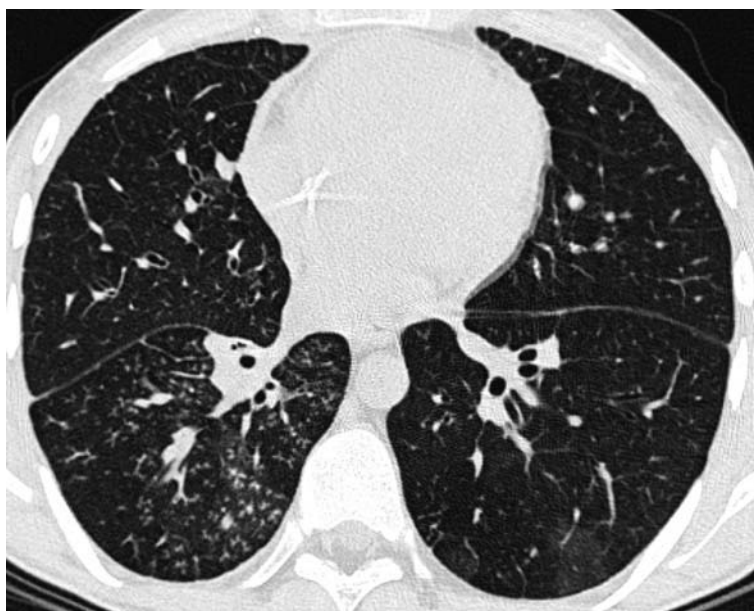
- Airways (peribronchiolar), air-space
- Patchy, diffuse (ground-glass), upper lobes can be more involved
- Centrilobular (nodules and ground-glass)

### Associated findings:

- Intralobular reticular pattern, irregular interlobular septal thickening, traction bronchiectasis and honeycombing when progressing to chronic stage

## References

- Hansell DM, Wells AU, Padley SP et al (1996) Hypersensitivity pneumonitis: correlation of individual CT patterns with functional abnormalities *Radiology* 199:123–128
- Hartman TE (2003) The HRCT features of extrinsic allergic alveolitis. *Semin Respir Crit Care Med* 24:419–426



22.1



22.2

## Case 22

CT shows multiple centrilobular nodules and intra-lobular branching lines often creating a tree-in-bud pattern in the right lower lobe. Also, thickening of the bronchial walls in the right lower lobe can be recognised.

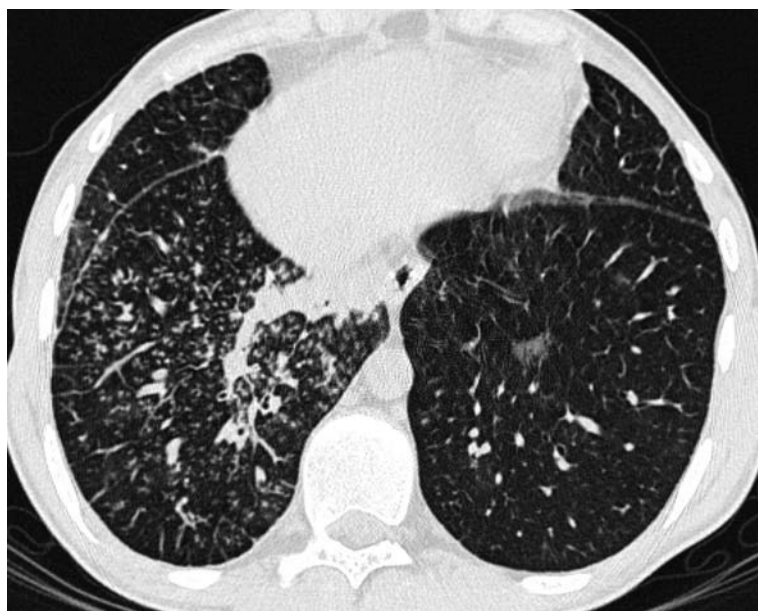
## Diagnosis

### Infectious bronchiolitis with tree-in-bud pattern

The term “bronchiolitis” refers to a broad morphologic spectrum of inflammatory events that are cen-

tred on small conducting airways. Bronchiolitis may be an isolated pathologic finding, although it is often a secondary consequence of diseases affecting other parts of the lung. Bronchiolitis can be characterised by a cellular inflammation in the wall of the bronchioles with filling of the lumen with mucus and exudates (acute bronchiolitis, cellular bronchiolitis, exudative bronchiolitis, infectious bronchiolitis) or can be characterised by submucosal collagenisation (fibrosis) with chronic narrowing (constrictive bronchiolitis, bronchiolitis obliterans, obliterative bronchiolitis). The term “infectious bronchiolitis” refers to the fact that infection is the most frequent





### CT Findings

#### Appearance patterns:

- Nodular and linear:
  - Well-defined or ill-defined nodules, rosettes of nodules
  - Ground-glass or soft-tissue density (airspace nodules)
  - Centrilobular branching lines (V- or Y-shaped)
  - Tree-in-bud

#### Distribution patterns:

- Airway, airspace
- Centrilobular
- Focal or diffuse, lobar

#### Associated findings:

- Bronchial wall thickening, bronchiectasis, bronchiolectasis
- Mosaic attenuation on inspiratory CT (chronic disease)
- Air trapping on expiratory CT (chronic disease)

### References

- Pipavath SJ, Lynch DA, Cool C et al (2005) Radiologic and pathologic features of bronchiolitis. *AJR Am J Roentgenol* 185:354–363
- Visscher DW, Myers JL (2006) Bronchiolitis: the pathologist's perspective. *Proc Am Thorac Soc* 3:41–47



cause of the cellular or acute bronchiolitis, although other stimuli such as aspiration, toxic fume and gases, drugs, cigarette smoking or diseases such as cystic fibrosis, chronic bronchitis and certain collagen vascular diseases can also cause acute or sub-acute inflammation of the bronchiolar wall.

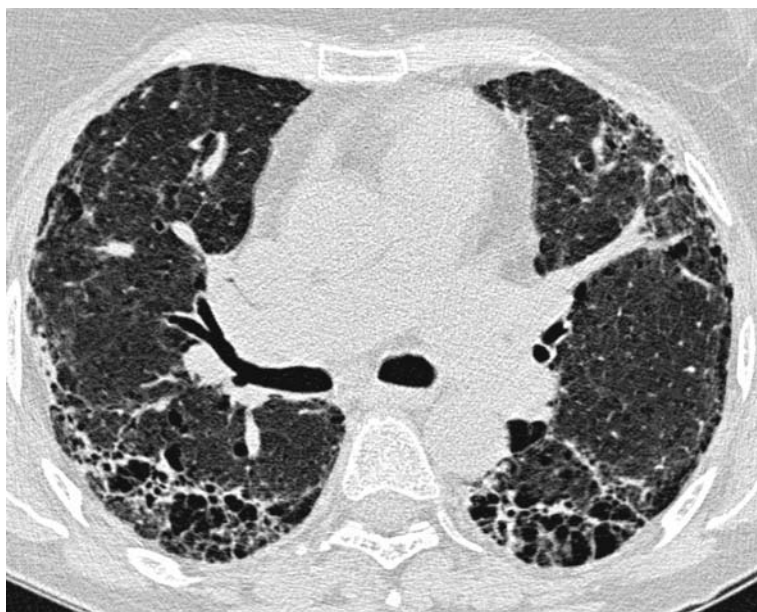
The tree-in-bud pattern is commonly seen at CT of the lungs. It consists of small centrilobular nodules of soft-tissue attenuation connected to multiple branching linear structures of similar calibre that originate from a single stalk. Originally reported in cases of endobronchial spread of mycobacterium tuberculosis, this pattern is now recognised as a CT

manifestation of many diverse entities. These entities include predominantly peripheral airway diseases such as infection (bacterial, fungal, viral), aspiration and cystic fibrosis, but also panbronchiolitis, organising pneumonia (proliferative bronchiolitis), connective tissue disorders (follicular bronchiolitis) and bronchioloalveolar carcinoma.





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**Case 23**

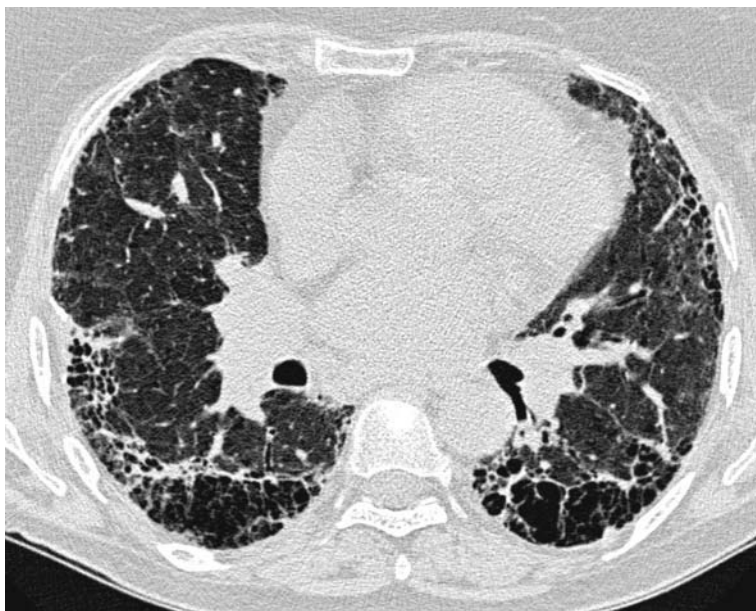
CT shows bilateral peripheral ground-glass opacities and areas of honeycombing.

**Diagnosis**

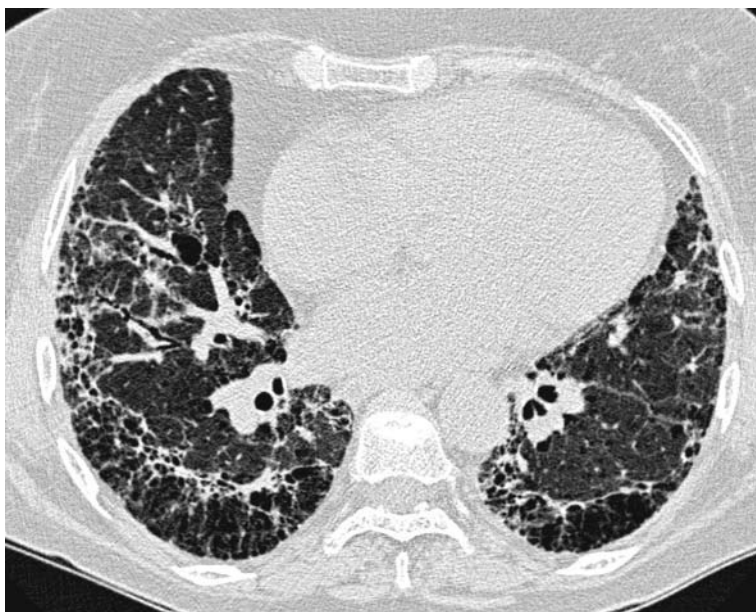
**Idiopathic pulmonary fibrosis (IPF), usual interstitial pneumonia (UIP)**

IPF is defined as a specific form of chronic fibrosing interstitial pneumonia of unknown cause, limited to the lungs and associated with a histologic pattern of UIP. It corresponds histologically with a typical variability in appearance: foci of normal lung alternating with areas that show a variable degree of interstitial inflammation and fibrosis. Disease tends

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## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (may indicate active disease when not associated with signs of fibrosis)
  - Crazy-paving (may indicate active disease when not associated with signs of fibrosis)
  - Consolidation
- Linear:
  - Septal lines, intralobular reticular pattern, peribronchovascular interstitial thickening, subpleural interstitial thickening
  - Early: smooth
  - Advanced: irregular
- Decreased attenuation:
  - Honeycombing

### Distribution patterns:

- Interstitium, airspace
- Bilateral patchy, dorsal subpleural, basal

### Associated findings:

- Traction bronchiectasis, bronchiolectasis
- Mediastinal lymph nodes
- Signs of pulmonary arterial hypertension

to be more prominent in the subpleural than in the central parenchyma, and is usually more severe in the basal region of the lower lobes.

## References

- Hunninghake GW, Zimmerman MB, Schwartz DA et al (2001) Utility of a lung biopsy for the diagnosis of idiopathic pulmonary fibrosis. *Am J Respir Crit Care Med* 164:193–196
- King TE Jr, Costabel U, Cordier J-F et al (2000) American Thoracic Society. Idiopathic pulmonary fibrosis: diagnosis and treatment. International consensus statement. American Thoracic Society (ATS), and the European Respiratory Society (ERS). *Am J Respir Crit Care Med* 161:646–664
- Souza CA, Muller NL, Flint J et al (2005) Idiopathic pulmonary fibrosis: spectrum of high-resolution CT findings. *AJR Am J Roentgenol* 185:1531–1539



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**Case 24**

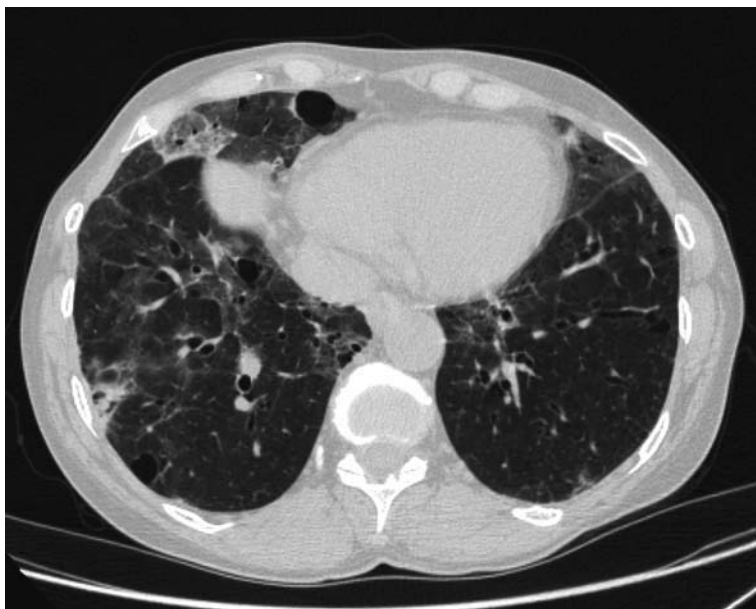
CT shows bilateral areas of ground-glass opacity, predominantly located in the lower lung fields. Small pulmonary cysts are also seen. In addition, there is mild thickening of the interlobular septa, which creates a crazy-paving pattern in the areas with the ground-glass opacity.

**Diagnosis****Lymphocytic interstitial pneumonia associated with Sjögren disease**

Lymphocytic interstitial pneumonia (LIP) is an uncommon lymphoproliferative disorder characterised by diffuse infiltration of the pulmonary interstitium, i.e. the alveolar walls, the interstitium surround-



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ing the intralobular vessels and airways and the (peri)lymphatic interstitium, by lymphocytes and plasma cells. A limited number of cysts can develop when bronchioles are partly obstructed by the lymphocytic infiltrate and overexpansion of the distal airspaces occurs. The distinction with low-grade lymphoma can be difficult. It occurs most commonly in patients with an underlying immunologic abnormality, particularly Sjögren syndrome and AIDS.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
- Linear:
  - Septal lines
  - Centrilobular branching lines
  - Peribronchovascular thickening
- Nodular:
  - Small, ill-defined nodules
- Decreased attenuation:
  - Scattered thin-walled cysts

### Distribution patterns:

- (Peri)lymphatic (nodules and lines): centrilobular, peribronchovascular, septal
- Interstitium (ground-glass): alveolar walls, surrounding intralobular vessels
- Lower lobes and subpleural areas

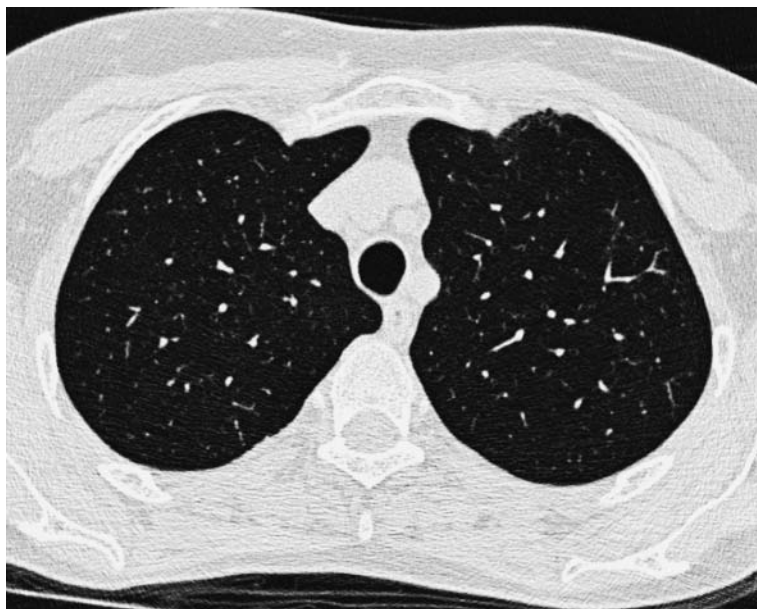
### Associated findings:

- Bronchiectasis (less common)
- Architectural distortion and honeycombing (less common)
- Mosaic perfusion (less common)
- Consolidation (possibility of lymphoma)

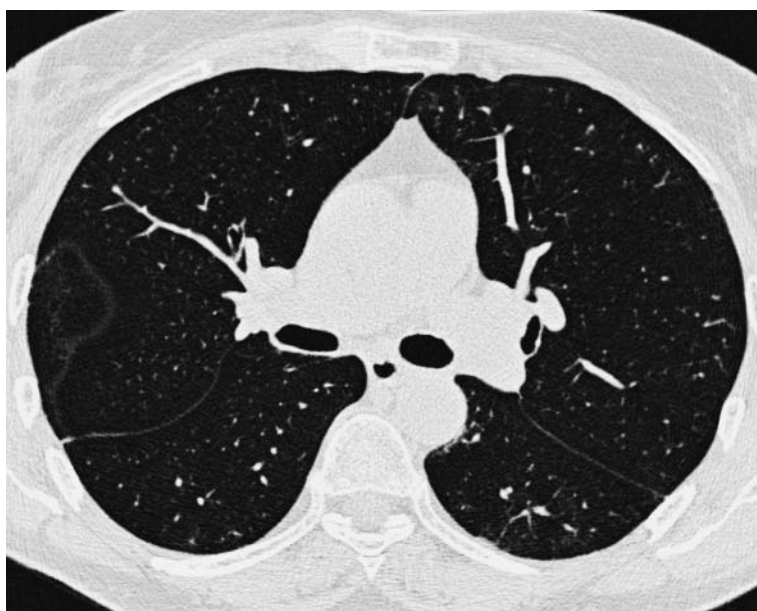
## References

- Dalvi V, Gonzalez EB, Lovett L (2006) Lymphocytic interstitial pneumonitis (LIP) in Sjögren's syndrome: a case report and a review of the literature. *Clin Rheumatol* 2006 Aug 5 (Epub ahead of print)
- Lohrmann C, Uhl M, Warnatz K et al (2004) High-resolution CT imaging of the lung for patients with primary Sjögren's syndrome. *Eur J Radiol* 52:137–143





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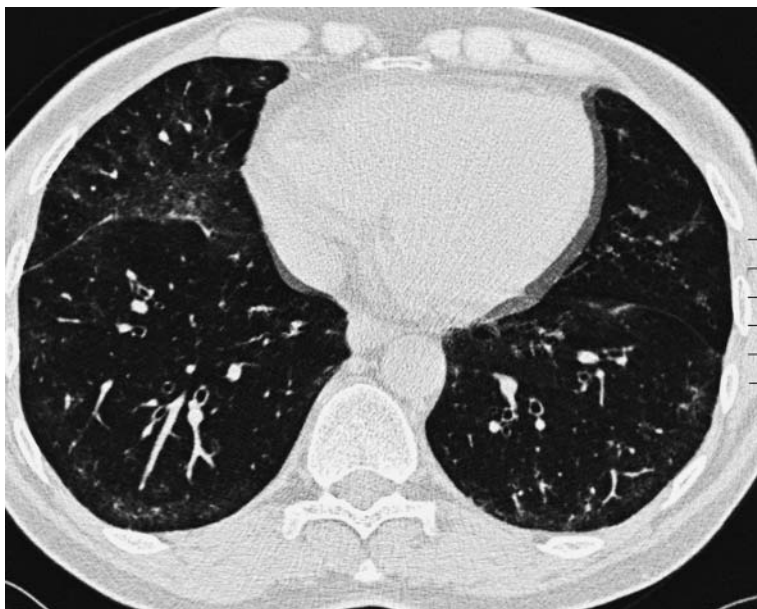
**Case 25**

Bilateral and peripheral patchy areas of ground-glass attenuation in the basal lung parts. In some areas, a faint intralobular reticular pattern can be recognised.

**Diagnosis****Scleroderma**

Progressive systemic sclerosis or scleroderma is an uncommon multisystem disorder with a female predominance. It can affect the skin and the internal organs (i.e. gastrointestinal tract, lung, heart, kidney and peripheral nervous system). The histologic features in the lung are those of nonspecific interstitial pneumonia or usual interstitial pneumonia. The disease is typically bilateral and most marked in the subpleural regions of the lung.

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## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass (may indicate active disease when not associated with signs of fibrosis)
  - Crazy-paving (may indicate active disease when not associated with signs of fibrosis)
- Linear:
  - Septal lines, intralobular branching lines, subpleural interstitial thickening
  - Parenchymal bands
  - Early: smooth
  - Advanced: irregular
- Decreased attenuation:
  - Honeycombing

### Distribution patterns:

- Interstitium, airspace
- Parenchymal abnormalities: lower lung zone predominance
- Honeycombing: uniform or peripheral distribution

### Associated findings:

- Traction bronchiectasis, bronchiolectasis
- Asymptomatic oesophageal dilatation
- Enlarged mediastinal lymph nodes
- Signs of pulmonary arterial hypertension

## References

- Devenyi K, Czirjak L (1995) High resolution computed tomography for the evaluation of lung involvement in 101 patients with scleroderma. *Clin Rheumatol* 14:633–640
- Generini S, Fiori G, Moggi Pignone A et al (1999) Systemic sclerosis. A clinical overview. *Adv Exp Med Biol* 455:73–83



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**Case 26**

Bilateral ground-glass opacities in the subpleural basal lung but also in the more central lung areas, with in some regions superposition of an intralobular reticular pattern (crazy-paving pattern). There are no signs of honeycombing.

**Diagnosis****Nonspecific interstitial pneumonia (NSIP) (cellular)**

NSIP is characterised histologically by interstitial inflammation and fibrosis without specific features that allow a diagnosis of usual interstitial pneumonia (UIP), desquamative interstitial pneumonia (DIP) or acute interstitial pneumonia (AIP). Since many cases of NSIP are idiopathic, the disease is considered one





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of the histological subtypes of idiopathic interstitial pneumonia. However, it can also be seen in association with connective tissue disease, hypersensitivity pneumonitis and a number of drugs. NSIP is typified by temporal homogeneity and less profusion of fibroblastic foci than is seen with UIP. Generally two groups are defined: cellular and fibrotic NSIP. Clinically patients with NSIP present with similar symptoms (cough and dyspnoea) when compared to patients with UIP, but have a better prognosis.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
  - Consolidation
- Linear:
  - Septal lines, intralobular reticular pattern
  - Crazy-paving

### Distribution patterns:

- Interstitium
- Patchy, confluent, bilateral
- Basal predominance

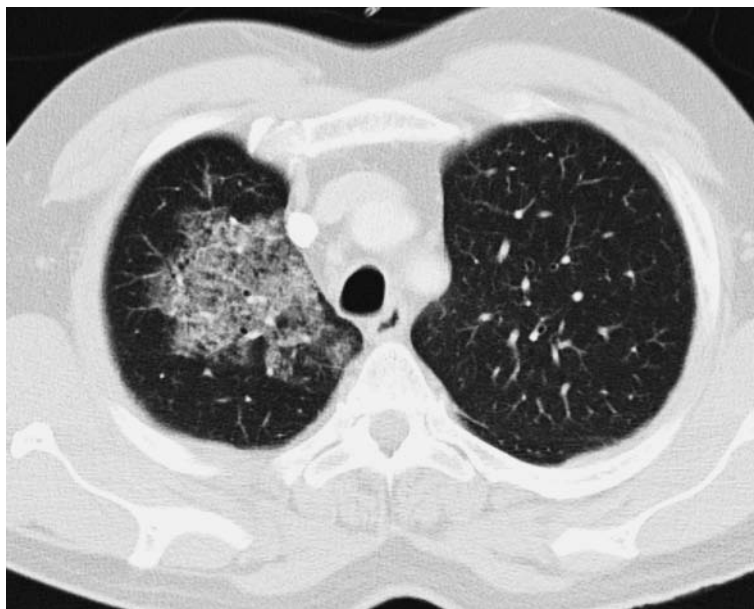
### Associated findings:

- Honeycombing and signs of fibrosis are rare but may be present
- Can mimic desquamative interstitial pneumonia (DIP), usual interstitial pneumonia (UIP), acute interstitial pneumonia (AIP) and organising pneumonia

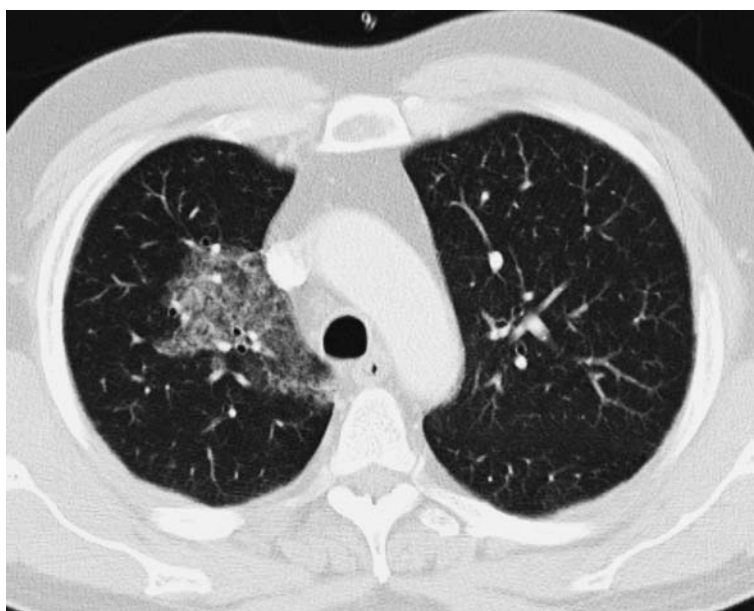
## References

- Bna C, Zompatori M, Poletti V et al (2005) Differential diagnosis between usual interstitial pneumonia (UIP) and non-specific interstitial pneumonia (NSIP) assessed by high-resolution computed tomography (HRCT). *Radiol Med (Torino)* 109:472–487
- Elliot TL, Lynch DA, Newell JD Jr (2005) High-resolution computed tomography features of nonspecific interstitial pneumonia and usual interstitial pneumonia. *J Comput Assist Tomogr* 29:339–345
- Flaherty KR, Martinez FJ, Travis W et al (2001) Nonspecific interstitial pneumonia (NSIP). *Semin Respir Crit Care Med* 22:423–434





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**Case 27**

Rather sharply defined area of ground-glass opacity in the right upper lobe associated with the presence of a linear (reticular) pattern consisting of septal lines and an intralobular reticular pattern creating a crazy-paving pattern.

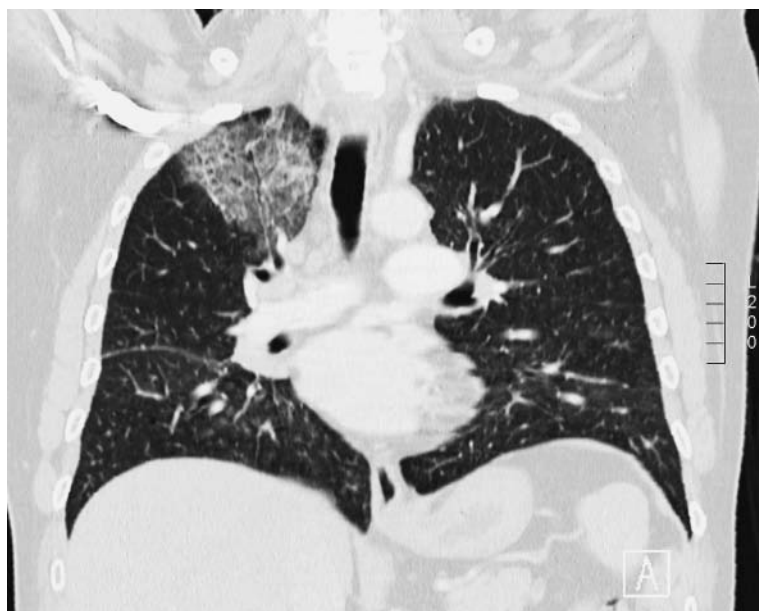
**Diagnosis****Pulmonary haemorrhage**

Pulmonary haemorrhage has a variety of causes, including infectious, neoplastic, idiopathic and Goodpasture's syndrome, inhalational, drugs, and sanguineous disorders.

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## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
  - Crazy-paving
  - Consolidation
- Linear:
  - Septal lines, intralobular reticular pattern

### Distribution patterns:

- Airspace
- No predominance except when idiopathic (perihilar, middle and lower lung, sparing apices and costophrenic angles)

### Associated findings:

- Bronchiectasis in case of recurrent infection
- Tumour

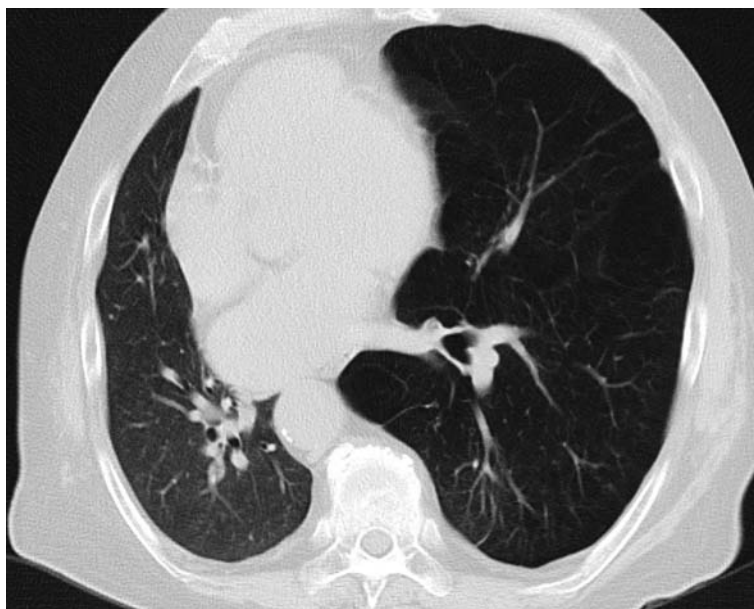
The crazy-paving pattern is a common finding at CT of the lungs and is caused by alveolar airspace filling with blood that has in a first stage preponderance at the periphery of the lobules and acini. With repeated episodes of haemorrhage, interlobular septal thickening and thickening of the intralobular interstitium can occur as a result of fibrosis. Consolidation is seen in case of complete airspace filling.

## Reference

Rossi SE, Erasmus JJ, Volpacchio M et al (2003) "Crazy-paving" pattern at thin-section CT of the lungs: radiologic-pathologic overview. *Radiographics* 23:1509–1519



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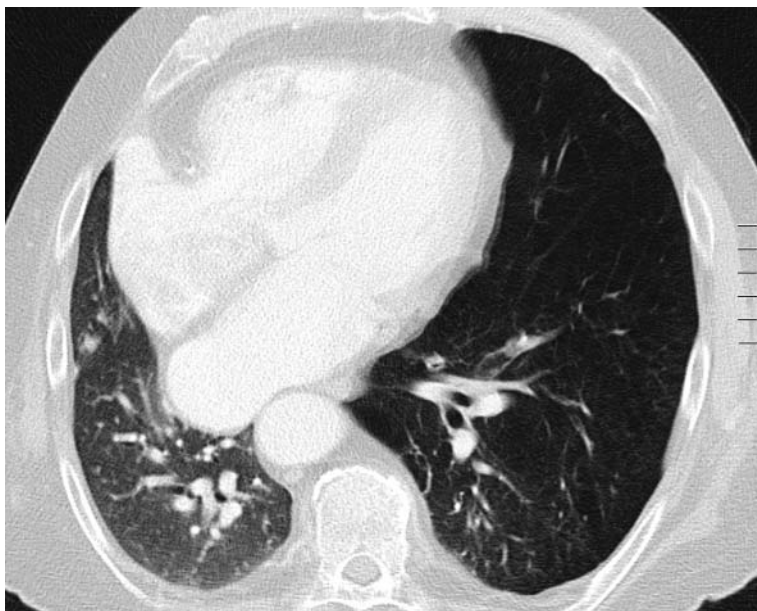
## Case 28

The middle and lower part of the native lung of a patient who underwent right-sided lung transplantation shows a diffuse decrease in lung attenuation associated with a reduction in number and size of the vascular markings.

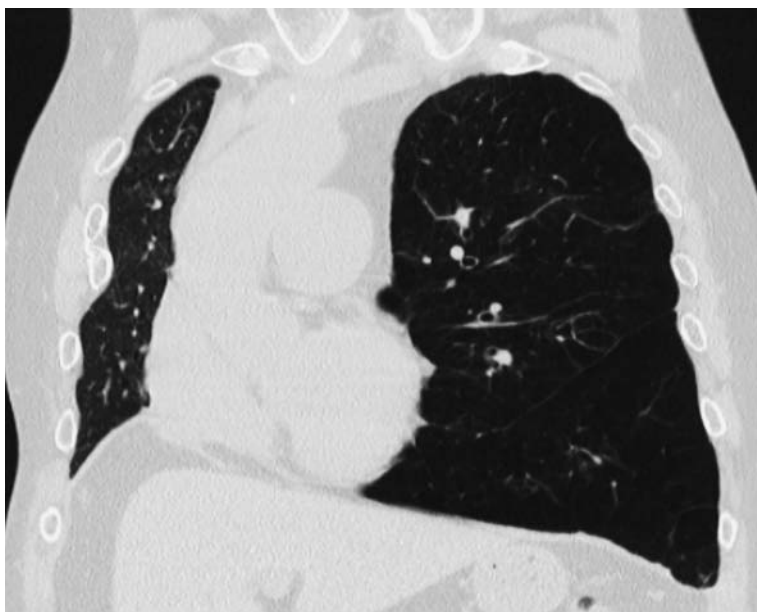
## Diagnosis

### Panlobular emphysema

The term “emphysema” refers to abnormal enlargement and destruction of distal spaces of the lung. Panlobular emphysema involves the entire acinus and typically all acini within the secondary pulmonary lobule. Diffuse panlobular emphysema is frequently associated with a genetic disease characterised by a severe deficit in alpha-1-antitrypsin (AAT).



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### CT Findings

#### Appearance patterns:

- Decreased attenuation

#### Distribution patterns:

- Airspace
- Lower lung

#### Associated findings:

- Reduction in size and number of vessels
- Parenchymal destruction in advanced disease

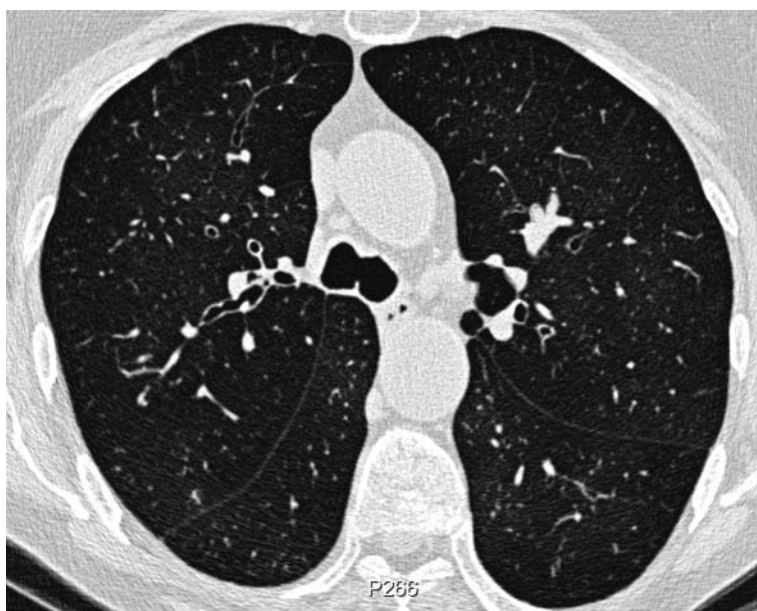
### Reference

Copley SJ, Wells AU, Muller NL et al (2002) Thin-section CT in obstructive pulmonary disease: discriminatory value. *Radiology* 223:812–819





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## Case 29

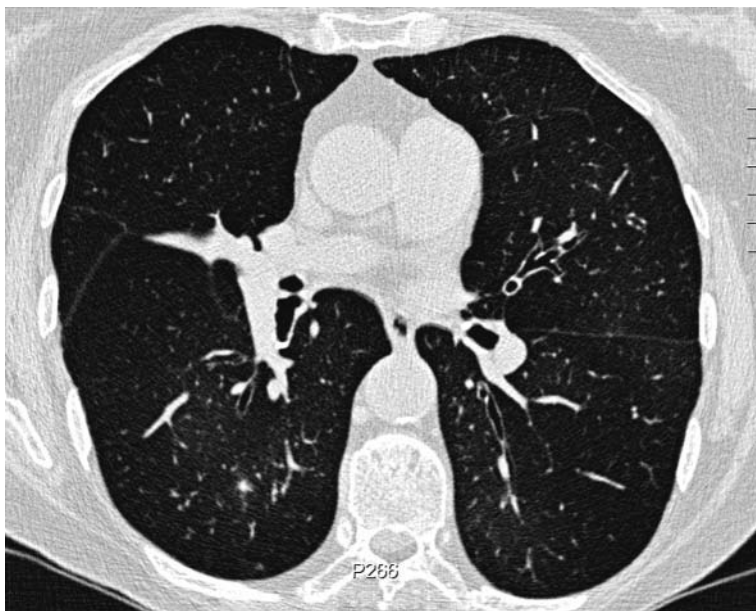
Bronchial wall thickening is seen in both lungs. Particularly the segmental and proximal subsegmental bronchi are involved and some bronchi are slightly dilated. In the left upper lobe, bronchi are filled, creating a Y-shaped opacity (gloved-finger opacity). A small number of centrilobular nodular opacities and centrilobular branching lines can be seen. There is also inhomogeneous lung perfusion (mosaic perfusion) and an area of lung consolidation in the middle lobe.

## Diagnosis

### Allergic bronchopulmonary aspergillosis

Allergic bronchopulmonary aspergillosis (ABPA) is a hypersensitivity response to *Aspergillus* antigens in the lung and is distinct from other forms of *Aspergillus* pulmonary disease. It is seen almost

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exclusively in asthmatic patients. *Aspergillus* spores germinate and proliferate in the proximal airways, which often show evidence of asthma-associated mucosal injury. The fungal hyphae increase mucus production and bronchial injury, which can result in bronchiectasis. Also distal bronchioles may be distended with mucus and their walls may show inflammatory changes.

## CT Findings

### Appearance patterns:

- Decreased attenuation:
  - Bronchiectasis (varicose or cystic)
  - Patchy areas of hypoventilation, hypoperfusion, creating a mosaic perfusion pattern
- Linear:
  - Bronchial wall thickening (segmental, proximal subsegmental bronchi)
  - Gloved-finger opacities: correspond to bifurcating opacities caused by the mucus-filled bronchi
  - Few centrilobular branching lines
- Nodular:
  - Few centrilobular nodules
  - Well-defined and ill-defined nodules
- Increased attenuation:
  - Ground-glass
  - Consolidation:
    - Transient consolidation, atelectasis

### Distribution patterns:

- Airways
- Bronchi: upper lobes, segmental and subsegmental bronchi
- Bronchioles: patchy

### Associated findings:

- Calcification of mucoid impactions

## Reference

Tillie-Leblond I, Tonnel AB (2005) Allergic bronchopulmonary aspergillosis. *Allergy* 60:1004–1013



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**Case 30**

Multiple areas of ground-glass attenuation with superposition of a linear pattern (septal lines and intralobular reticular pattern) creating a crazy-paving pattern are seen in both lungs. The changes are patchy and show a geographic patchwork appearance.

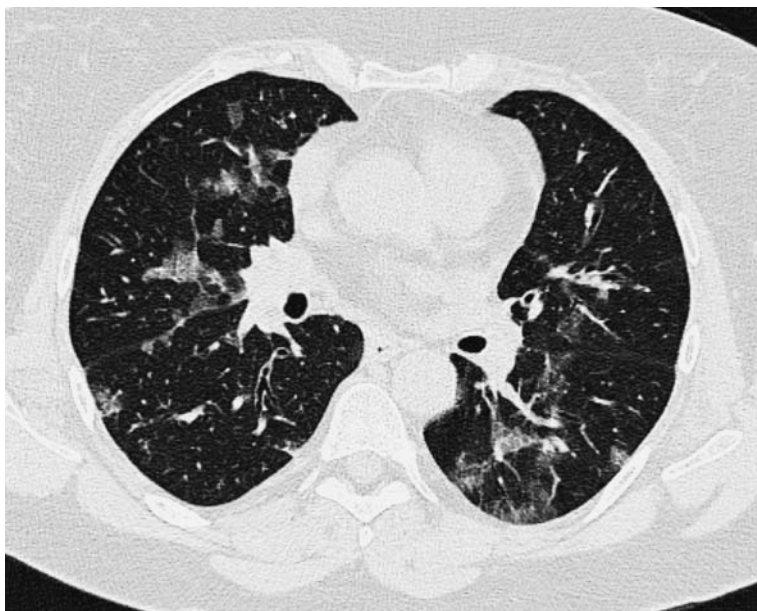
**Diagnosis**

***Pneumocystis Jiroveci* pneumonia**  
(*Pneumocystis Carinii* pneumonia)

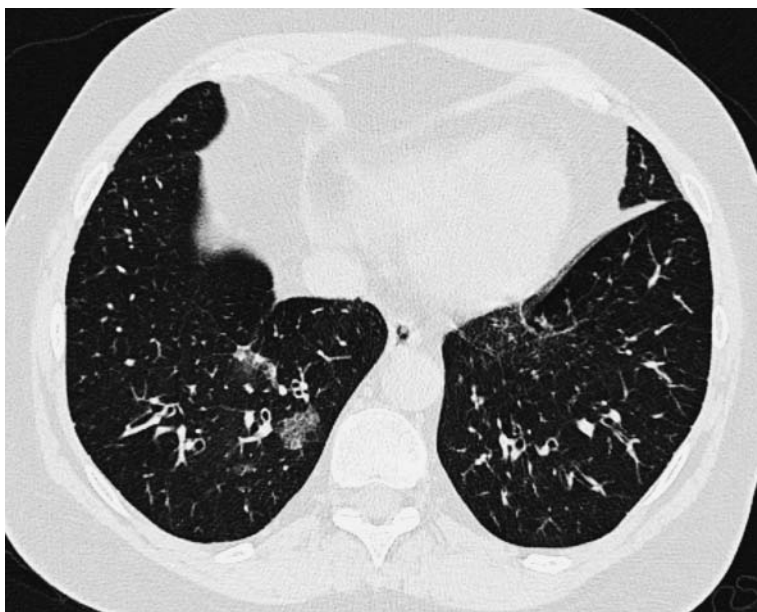
Pneumonia due to *Pneumocystis* is an important cause of morbidity and mortality among immunodepressed patients (AIDS, lymphoproliferative dis-



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orders, organ and bone marrow transplants). Cyst formation is seen in 30% of patients and believed to be the result of necrosis and cavitation of the lung parenchyma. Advances in molecular biology have led to the modification of the taxonomic classification of this atypical fungus and change in the name of the *Pneumocystis* responsible for the infection in humans, which is now called *Pneumocystis jirovecii*.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
- Linear:
  - Septal lines, intralobular reticular pattern (20% of patients)
  - Crazy-paving
- Decreased attenuation:
  - Small cystic lesions (30% of patients):
    - Size: 5 mm to 3 cm
    - Thin-walled

### Distribution patterns:

- Airspace
- Patchy, geographic distribution
- Cysts: upper lobes

### Associated findings:

- Airspace consolidation
- Thickening of peripheral pulmonary vessels
- Nodules, miliary pattern (uncommon)

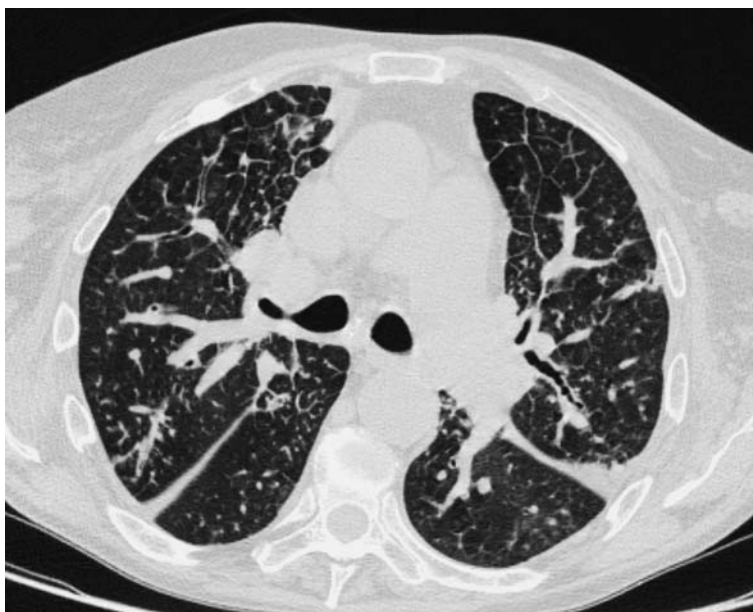
## References

- Hidalgo A, Falco V, Mauleon S et al (2003) Accuracy of high-resolution CT in distinguishing between *Pneumocystis carinii* pneumonia and non-*Pneumocystis carinii* pneumonia in AIDS patients. *Eur Radiol* 13:1179–1184
- Varela Aguilar JM, Medrano Ortega FJ, Calderon Sandubete E (2006) *Pneumocystis jirovecii*: a new name for an old pathogen. *Rev Clin Esp* 206:278–280





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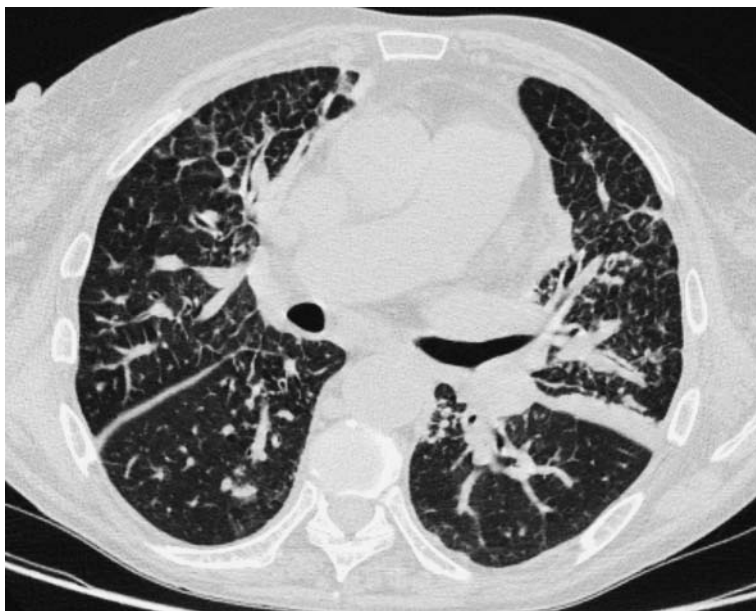
**Case 31**

Patchy distribution of areas of ground-glass attenuation in both lungs and several centrilobular nodular opacities. In addition, multiple septal lines, peribronchovascular thickening and a pleural effusion are seen.

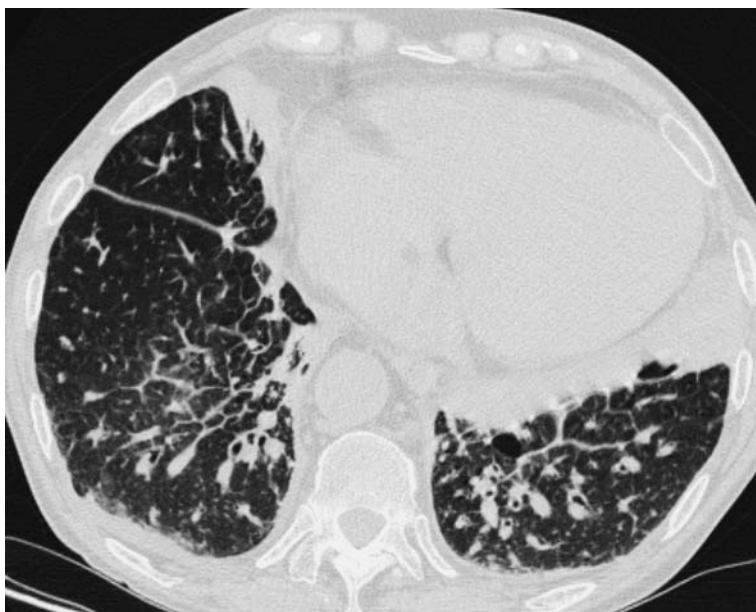
**Diagnosis****Churg-Strauss syndrome**

Churg-Strauss syndrome, together with Wegener's granulomatosis and microscopic polyangiitis, is one of the anti-neutrophil cytoplasmic antibodies (ANCA)-associated vasculitides. It is characterised clinically by fever, asthma and

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blood eosinophilia and pathologically by necrotising vasculitis of the medium and small vessels including capillaries, which is manifested by a transmural cellular infiltrate of predominantly eosinophils and extravascular granulomatous inflammation. Alveolar interstitial and airspace infiltration by eosinophils and macrophages is also frequent. Cardiac involvement can cause pulmonary oedema.

## CT Findings

### Appearance patterns:

- Increased attenuation (as a result of interstitial and airspace infiltration by eosinophils and macrophages):
  - Ground-glass
  - Consolidation
  - Crazy-paving
- Nodular patterns (as a result of granulomatous inflammation):
  - Small centrilobular (interstitial nodule)
  - Conglomerate nodules and masses
- Linear (as a result of pulmonary oedema secondary to cardiac involvement and interstitial infiltration of eosinophils):
  - Septal lines
  - Peribronchovascular thickening
- Decreased attenuation:
  - Masses may cavitate

### Distribution patterns:

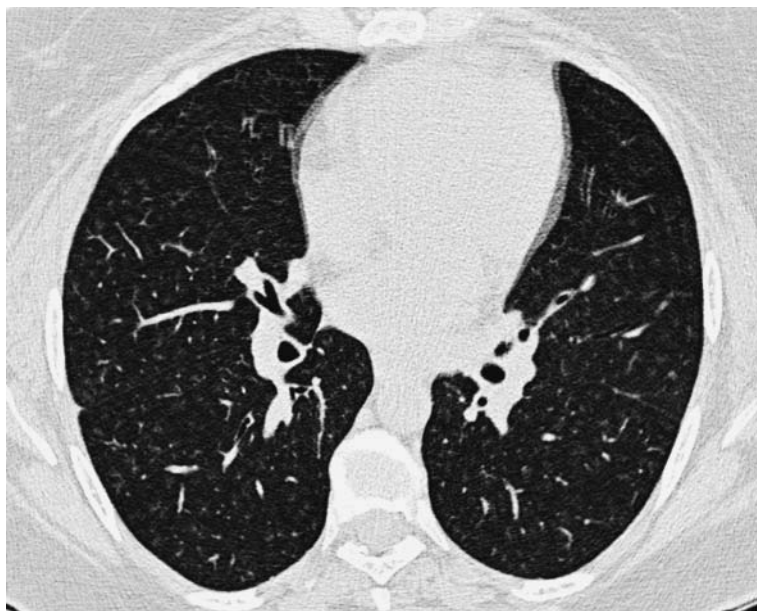
- Airspace, interstitium ((peri)vascular)
- Patchy, subpleural (ground-glass, consolidation)
- Centrilobular (small nodules)

### Associated findings:

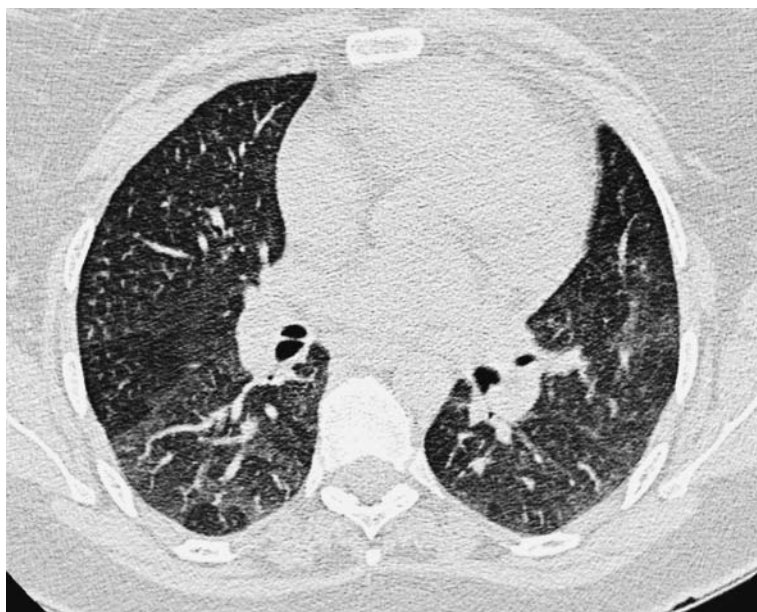
- Enlargement of the peripheral pulmonary arteries
- Increased cardiac size
- Adenopathy is not common and is more suggestive of infection or malignancy

## References

- Brown KK (2006) Pulmonary vasculitis. *Proc Am Thorac Soc* 3:48–57
- Keogh KA, Specks U (2006) Churg-Strauss syndrome: update on clinical, laboratory and therapeutic aspects. *Sarcoidosis Vasc Diffuse Lung Dis* 23:3–12
- Silva CI, Muller NL, Fujimoto K et al (2005) Churg-Strauss syndrome: high resolution CT and pathologic findings. *J Thorac Imaging* 20:74–80



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**Case 32**

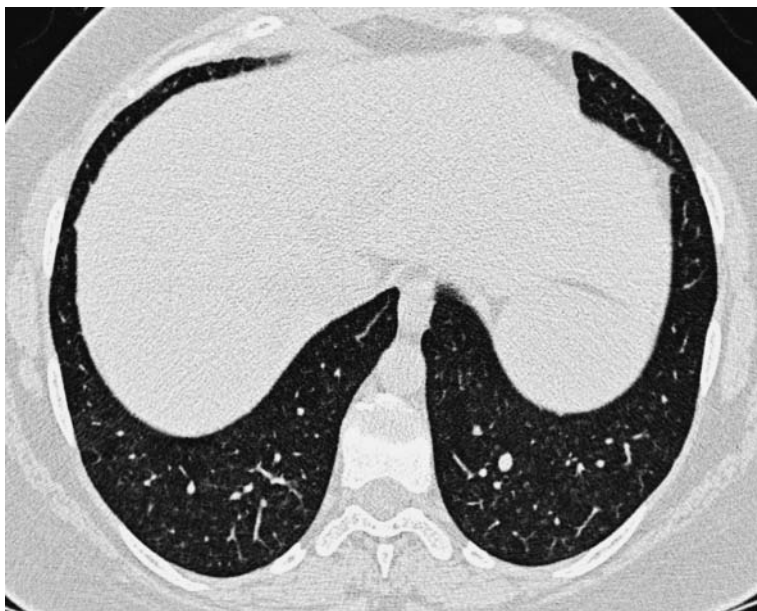
CT shows diffuse partly well-defined and partly ill-defined, centrilobular ground-glass opacities and branching lines. Abnormal high-density increase of the lung parenchyma together with several areas of air trapping is seen on the expiratory scans (32.2 and 32.4).

**Diagnosis****(Subacute) hypersensitivity pneumonitis**

Hypersensitivity pneumonitis, also known as extrinsic allergic alveolitis, is an allergic lung disease caused by the inhalation of antigens contained in a



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variety of organic dusts. Histologic abnormalities are alveolar interstitial thickening by mononuclear infiltrate, bronchiolitis (small bronchioles down to the proximal respiratory bronchioles) and small granulomas in the peribronchiolar interstitium. Proteinaceous exudates may be present.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
- Nodular:
  - Usually ill-defined nodules
  - Ground-glass density, sometimes soft tissue density
- Linear (less frequent):
  - Centrilobular branching lines
- Decreased attenuation:
  - Air trapping
  - Mosaic perfusion

### Distribution patterns:

- Airways (peribronchiolar), air-space
- Patchy, diffuse (ground-glass), upper lobes can be more involved
- Centrilobular (nodules and ground-glass)

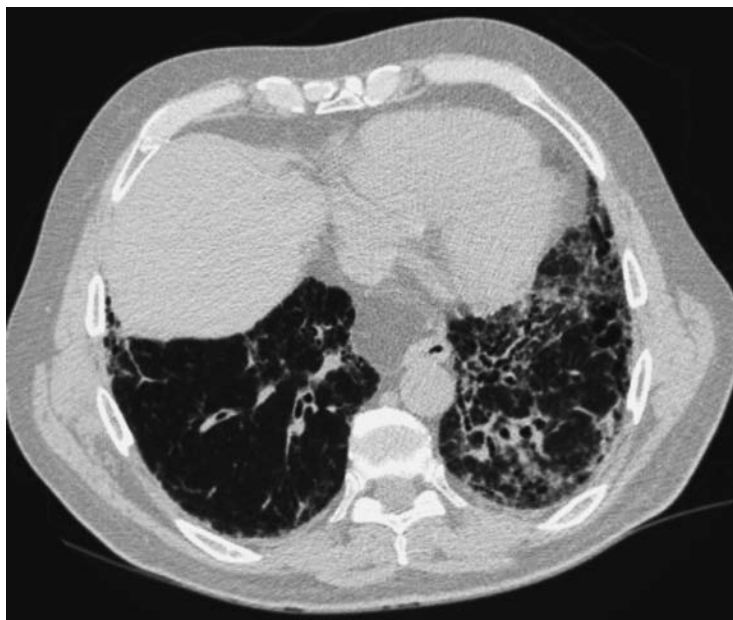
### Associated findings:

- Intralobular reticular pattern, irregular interlobular septal thickening, traction bronchiectasis and honeycombing when progressing to chronic stage

## References

- Hansell DM, Wells AU, Padley SP et al (1996) Hypersensitivity pneumonitis: correlation of individual CT patterns with functional abnormalities. *Radiology* 199:123–128
- Hartman TE (2003) The HRCT features of extrinsic allergic alveolitis. *Semin Respir Crit Care Med* 24:419–426





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### Case 33

Areas of ground-glass opacity and crazy-paving in both lungs. There is some preference for the peripheral subpleural lung regions, but also other parts of the lung are involved. There are signs of fibrosis: traction bronchiectasis and distortion of the lung parenchyma.

### Diagnosis

#### Nonspecific interstitial pneumonia (NSIP) (fibrotic)

NSIP is characterised histologically by interstitial inflammation and fibrosis without specific features that allow a diagnosis of usual interstitial pneumonia (UIP), desquamative interstitial pneumonia (DIP) or acute interstitial pneumonia (AIP). Since many cases of NSIP are idiopathic, the disease is considered one of the histologi-



### CT Findings

#### Appearance patterns:

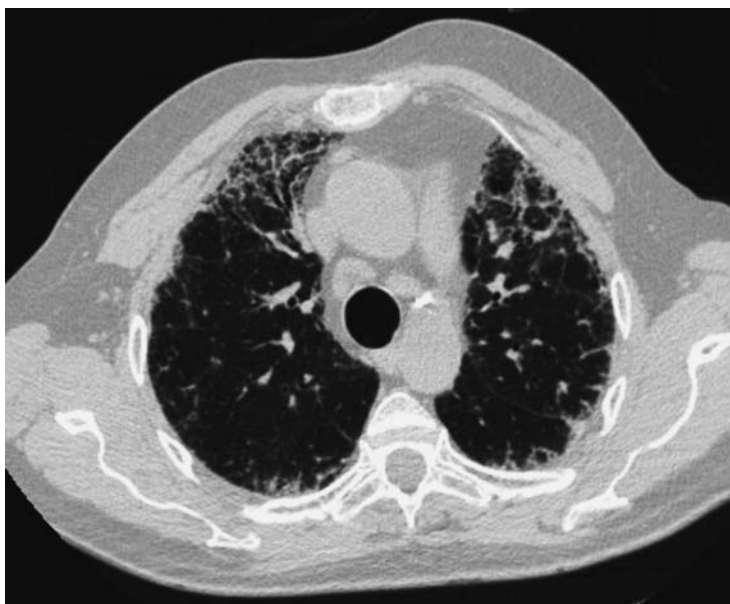
- Increased attenuation:
  - Ground-glass
  - Crazy-paving
  - Consolidation
- Linear:
  - Septal lines, intralobular reticular pattern
  - Crazy-paving

#### Distribution patterns:

- Interstitium
- Patchy, confluent, bilateral
- Basal predominance

#### Associated findings:

- Honeycombing and signs of fibrosis are rare but may be present
- Can mimic desquamative interstitial pneumonia (DIP), usual interstitial pneumonia (UIP), acute interstitial pneumonia (AIP) and organising pneumonia



cal subtypes of idiopathic interstitial pneumonia. However, it can also be seen in association with connective tissue disease, hypersensitivity pneumonitis and a number of drugs. NSIP is typified by temporal homogeneity and less profusion of fibroblastic foci than is seen with UIP. Generally two groups are defined: cellular and fibrotic NSIP. Clinically patients with NSIP present with similar symptoms (cough and dyspnoea) when compared to patients with UIP, but have a better prognosis.

### References

- Bna C, Zompatori M, Poletti V et al (2005) Differential diagnosis between usual interstitial pneumonia (UIP) and non-specific interstitial pneumonia (NSIP) assessed by high-resolution computed tomography (HRCT). *Radiol Med (Torino)* 109:472–487
- Elliot TL, Lynch DA, Newell JD Jr (2005) High-resolution computed tomography features of nonspecific interstitial pneumonia and usual interstitial pneumonia. *J Comput Assist Tomogr* 29:339–345
- Flaherty KR, Martinez FJ, Travis W et al (2001) Nonspecific interstitial pneumonia (NSIP). *Semin Respir Crit Care Med* 22:423–434

## Case 34

Both on inspiratory (34.1, 34.2, 34.3) and expiratory scans (34.4, 34.5, 34.6), inhomogeneous lung attenuation with predominantly peripheral areas of decreased lung density and reduction in blood vessel calibre, surrounded by areas of increased lung density and normal or increased vessel calibre is seen: mosaic perfusion. Both low- and high-density areas increase in density and decrease in volume at deep expiration, i.e. there is no obvious air trapping. Note also the dilatation of the central pulmonary arteries.

### Diagnosis

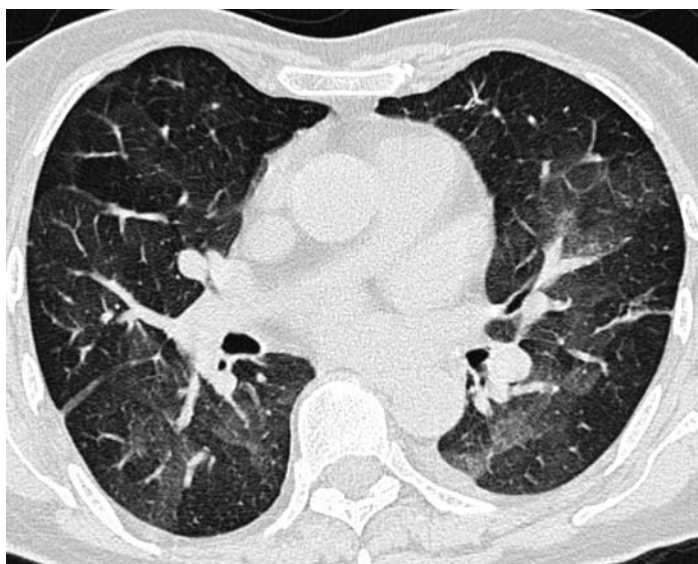
**Mosaic pattern secondary to obstruction of small arteries (mosaic perfusion) in a patient with chronic pulmonary embolism**

A mosaic pattern caused by mosaic perfusion can be caused by small airway narrowing or narrowing or obstruction of small arteries. Small airway narrowing is the most frequent cause and the findings are most common in patients with bronchiolitis obliterans (constrictive bronchiolitis) and diseases associated with small airway obstruction.

However, a combination of reduced peripheral perfusion and mosaic perfusion with enlargement of the central pulmonary arteries suggests a vascular cause, i.e. chronic pulmonary embolism with pulmonary arterial hypertension.



34.1



34.2



34.3



34.4



34.5



34.6



## CT Findings

### Appearance patterns:

- Decreased attenuation:
  - Hypoperfusion
  - Mosaic perfusion
- Increased attenuation:
  - Ground-glass by an increase in parenchymal perfusion (redistribution of flow)

### Distribution patterns:

- Vascular
- Patchy or mosaic, peripheral lung

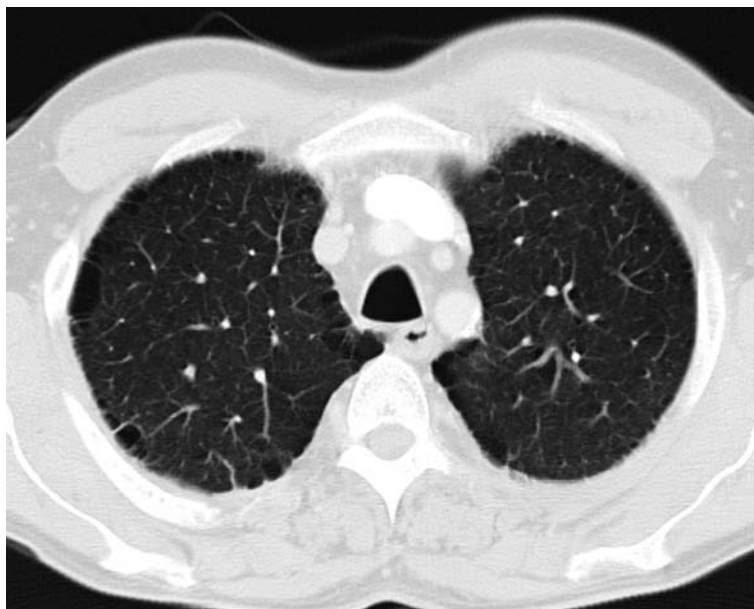
### Associated findings:

- Enlargement of the central pulmonary arteries (signs of pulmonary arterial hypertension)
- Chronic clot in pulmonary arteries

## Reference

King MA, Bergin CJ, Yeung DW et al (1994) Chronic pulmonary thromboembolism: detection of regional hypoperfusion with CT. *Radiology* 191:359–363





35.1



35.2

**Case 35**

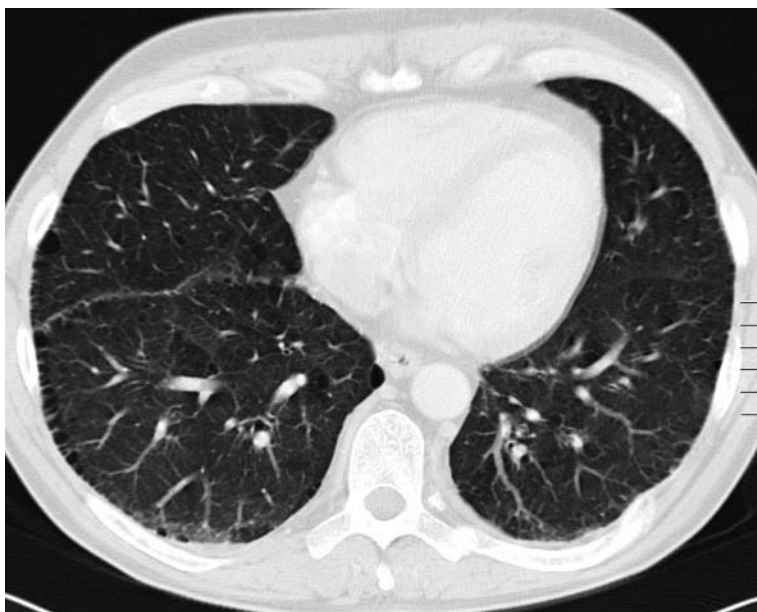
Multiple small, subpleural areas of very low density are seen in both lungs. These areas are organised in a single layer and have no wall or a thin wall. There is upper lung predominance.

**Diagnosis****Paraseptal emphysema**

Emphysema is defined as a permanent, abnormal enlargement of airspaces distal to the terminal bronchiole, accompanied by the destruction of the walls of the involved airspaces. Paraseptal emphysema is characterised by involvement of the distal part of the secondary pulmonary lobule and is therefore most striking in a subpleural location.



35.3



35.4

## CT Findings

### Appearance patterns:

- Decreased attenuation:
  - Multiple, small areas of very low attenuation, often with very thin walls corresponding to interlobular septa

### Distribution patterns:

- Airspace
- Lung periphery
- Upper lung

### Associated findings:

- Some fibrosis may be present
- Often associated with centrilobular emphysema

## Reference

Snider GL (1994) Pathogenesis and terminology of emphysema. *Am J Respir Crit Care Med* 149:1382–1383

## Case 36

Areas of increased and decreased lung density are seen in both lungs (mosaic pattern). The larger calibre of the vessels in the high-density areas compared to the low-density areas suggests mosaic perfusion as the cause of the mosaic pattern.

On expiratory scans (36.4, 36.5, 36.6) there is an accentuation of the difference in attenuation, indicating air trapping and suggesting small airway narrowing. Note the bronchial wall thickening.

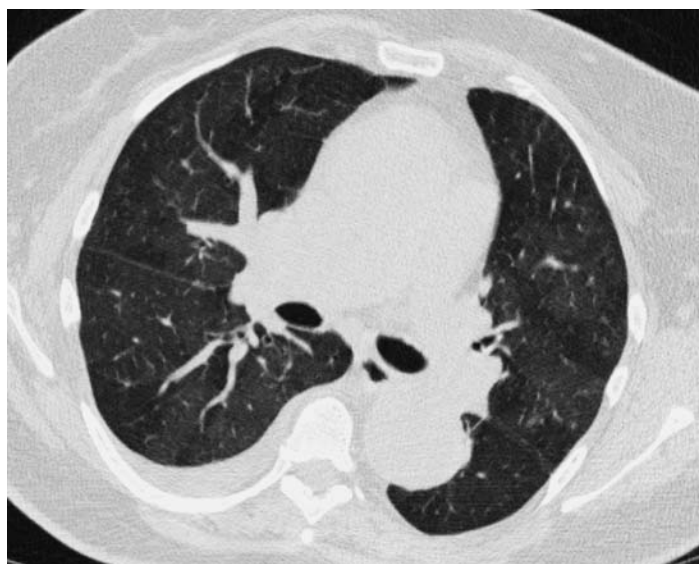
## Diagnosis

**Mosaic pattern and air trapping secondary to small airway narrowing (mosaic perfusion) in a patient with graft-versus-host disease**

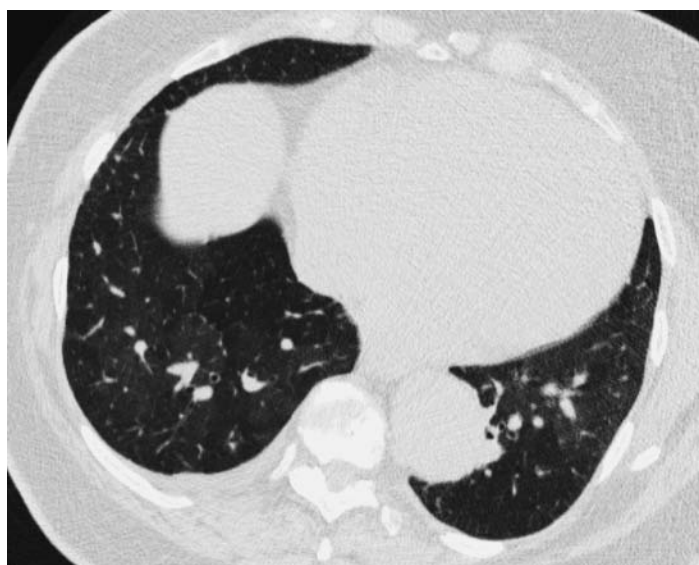
A mosaic pattern caused by mosaic perfusion can be due to small airway narrowing or to narrowing or obstruction of small arteries. Small airway narrowing is the most frequent cause and the findings are most common in patients with bronchiolitis obliterans (constrictive bronchiolitis) and diseases associated with small airway obstruction. The small airway narrowing causes reflector vasoconstriction and reduction of capillary blood volume. Redistribution of blood flow to the normal surrounding areas is responsible for the increased perfusion in these areas. Air trapping is defined as abnormal retention of gas within a lung or within lung units following expiration. It is caused by early collapse of the small airways during expiration and is diagnosable if lung parenchyma remains lucent on postexpiratory CT, shows a less than normal increase in attenuation following expiration, or shows little change in cross-sectional area. Air trapping cannot be diagnosed on inspiratory scans: lung inhomogeneity on inspiratory scans in patients with airway disease should preferably be referred to as a mosaic pattern.



36.1



36.2



36.3





36.4



36.5



36.6

## CT Findings

### Appearance patterns:

- Decreased attenuation:
  - Hypoperfusion
  - Mosaic perfusion
  - Air trapping
- Increased attenuation:
  - Ground-glass by increase of parenchymal perfusion (redistribution of flow)

### Distribution patterns:

- Airways
- Patchy, peripheral lung
- Varying sizes:
  - Secondary pulmonary lobules, segment (bronchiolar narrowing)
  - Lobes, entire lung (bronchial narrowing)

### Associated findings:

- Signs of bronchial pathology

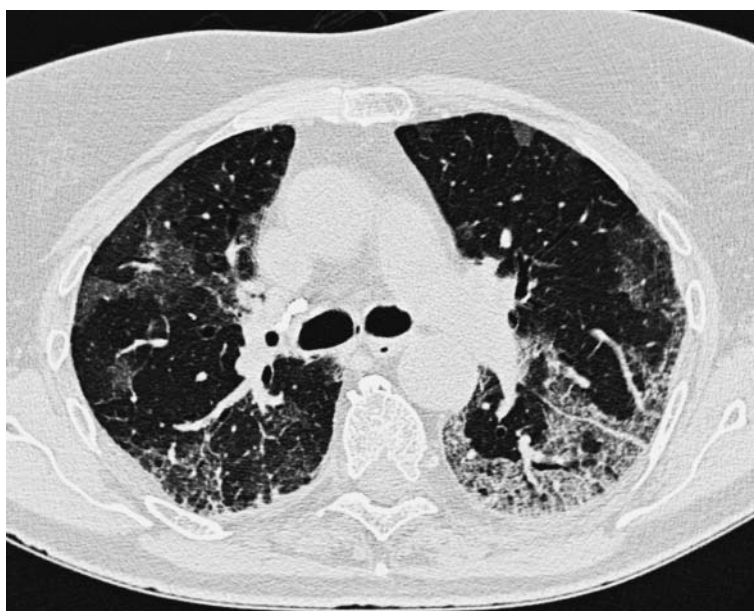
## References

- Webb WR (1997) Radiology of obstructive pulmonary disease. *AJR Am J Roentgenol* 169:637–647
- Worthy SA, Müller NL, Hartman TE et al (1997) Mosaic attenuation pattern on thin-section CT scans of the lung: differentiation among infiltrative lung, airway, and vascular diseases as a cause. *Radiology* 205:465–470





37.1



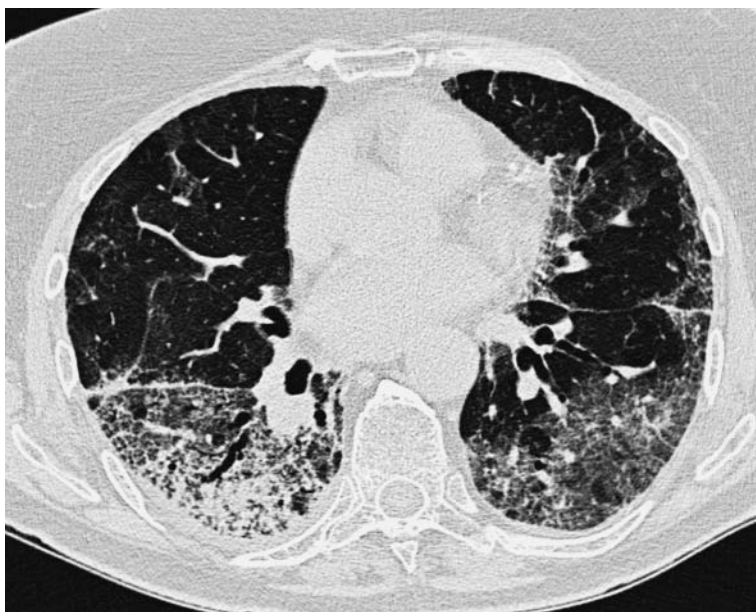
37.2

**Case 37**

Bilateral areas of consolidation, ground-glass opacity and crazy-paving are seen involving almost exclusively the subpleural lung regions.

**Diagnosis****Chronic eosinophilic pneumonia**

Patients with chronic eosinophilic pneumonia usually present with a history of cough lasting a few months, shortness of breath and fever. The predominant histologic finding is filling of the alveolar airspaces with an inflammatory infiltrate containing a high proportion of eosinophils. There is usually also a cellular infiltration of the interstitium. Blood eosinophilia is usually present.



## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass
  - Crazy-paving
  - Consolidation
- Linear:
  - Interlobular septal thickening, intralobular reticular pattern

### Distribution patterns:

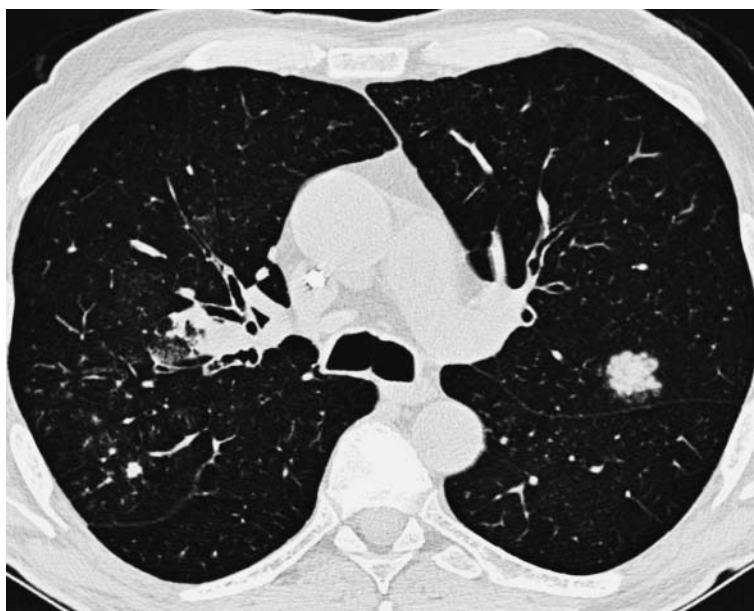
- Airspace, interstitium
- Patchy, bilateral
- Peripheral predominance

### Associated findings:

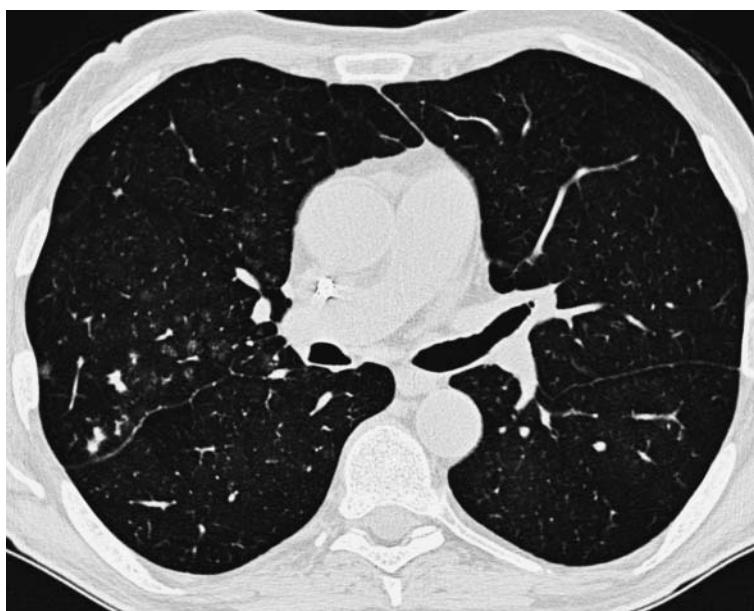
- Bronchial wall thickening
- Parenchymal bands

## Reference

Johkoh T, Muller NL, Akira M et al (2000)  
Eosinophilic lung diseases: diagnostic accuracy of thin-section CT in 111 patients. *Radiology* 216:773–780



38.1



38.2

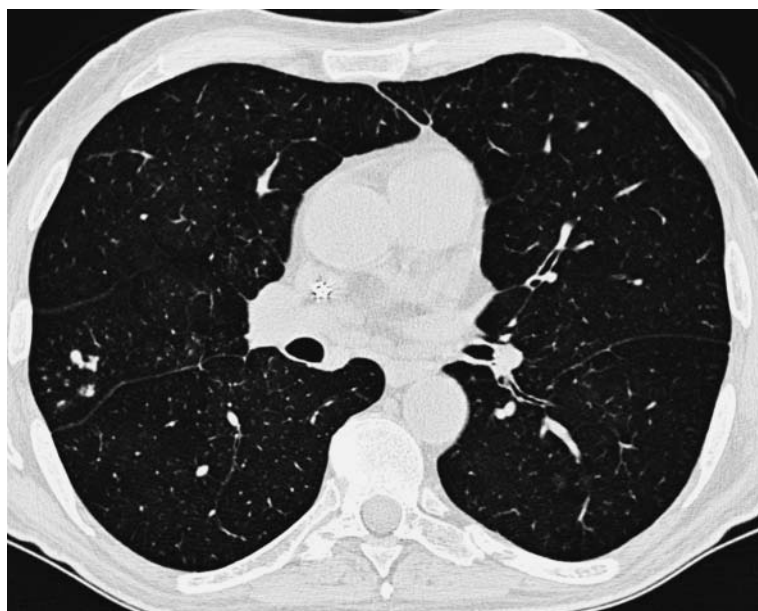
**Case 38**

Several small nodular opacities are seen in both lungs. Most nodules are randomly distributed, although some show a centrilobular location. In both upper lungs, larger irregular nodular opacities are seen. In addition, several small areas of ground-glass opacity can be recognised.

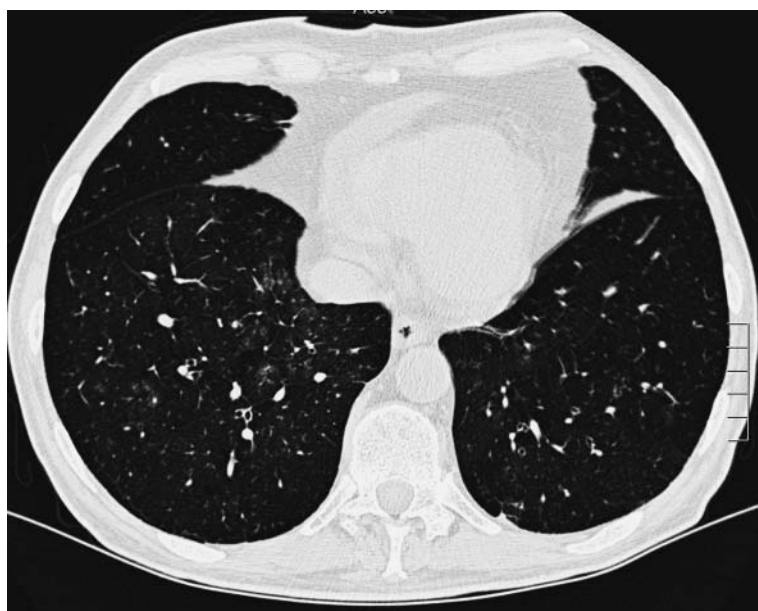
**Diagnosis****Wegener granulomatosis**

Wegener granulomatosis (WG) is a systemic disease of unknown aetiology characterised by necrotising granulomatous inflammation, tissue necrosis and variable degrees of vasculitis in small and medium-sized arteries and veins. The classic clinical pattern is a triad involving the upper airways, lungs and kidneys.





38.3



38.4

## CT Findings

### Appearance patterns:

- Nodular:
  - Well-defined (interstitial nodule)
  - Size: 0.5–4 cm
- Increased attenuation:
  - Ground-glass (pulmonary haemorrhage or small necrotising granulomas)
  - Consolidation (pulmonary haemorrhage or necrotising granulomatous inflammation)
- Decreased attenuation:
  - Nodules may cavitate

### Distribution patterns:

- Interstitium, airspace
- Nodules or masses: multiple, bilateral, random, sometimes predominantly centrilobular, subpleural or peribronchovascular
- Patchy areas of consolidation and ground-glass opacity

### Associated findings:

- Involvement of the trachea and bronchial tree
- Mediastinal adenopathy
- Mosaic perfusion and air trapping
- Pleural effusion

## References

- Lee KS, Kim TS, Fujimoto K et al (2005) Thoracic manifestation of Wegener's granulomatosis: CT findings in 30 patients. *Eur Radiol* 13:43–51
- Lohrmann CU, Schaefer O, Ghanem N et al (2005) Serial high-resolution computed tomography imaging in patients with Wegener granulomatosis: differentiation between active inflammatory and chronic fibrotic lesions. *Acta Radiol* 46:484–491



### Case 39

CT shows multiple areas of ground-glass attenuation, crazy-paving and consolidation in both lungs. Some are located at the lung periphery, some have a more axial peribronchovascular distribution.

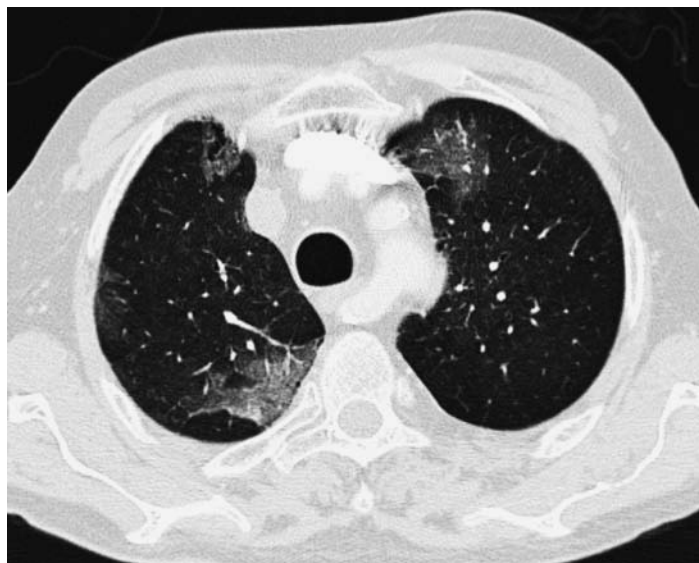
### Diagnosis

#### **Drug-induced pneumonitis (amiodarone induced nonspecific interstitial pneumonia)**

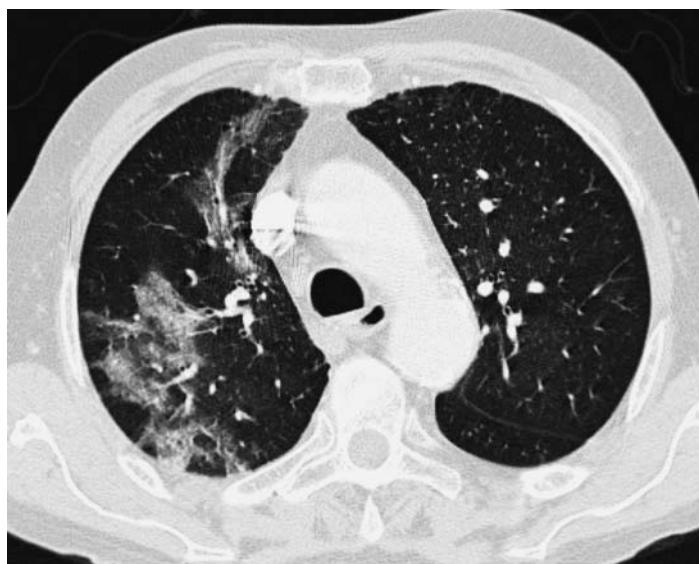
Amiodarone is a drug used in the treatment of cardiac arrhythmias that is deposited in the lungs and that can cause different types of interstitial pneumonitis (nonspecific interstitial pneumonia, diffuse alveolar damage and organising pneumonia). Because amiodarone contains high iodine by weight, it has a high attenuation value on CT. Therefore CT usually provides confident recognition of drug deposition within pulmonary and other tissues. In particular, an increased liver and spleen attenuation can be seen (39.4).

Also, many other drugs can be responsible for drug-induced pulmonary injury manifested by a wide variety of histologic reactions, each of which has its corresponding CT features. However, none of these histologic reactions is specific. As a result, the diagnosis of drug-induced pulmonary disease is predominantly based on a combination of radiological and clinical findings, sometimes completed with histologic findings in a patient who has received drugs known to cause the abnormalities.

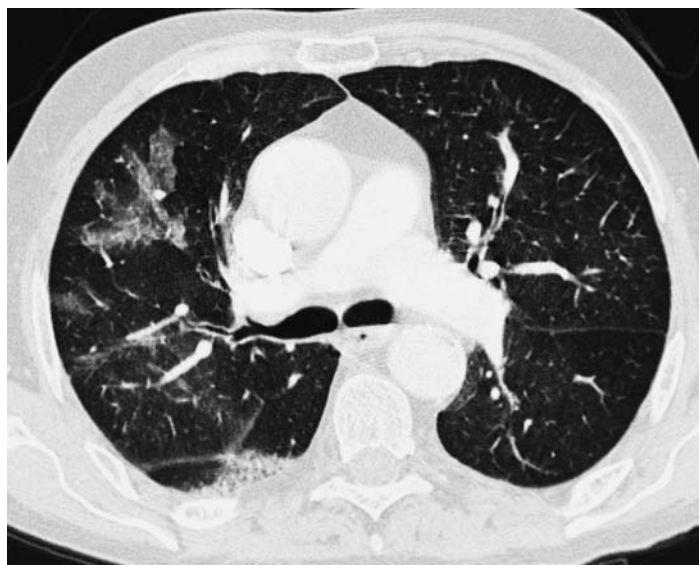
Table 8.2 reviews the most frequently occurring histologic reactions in the lung that can be seen in association with the use of certain drugs.



39.1



39.2



39.3



39.4

Table 8.2. Most frequently occurring histologic reactions in the lung that can be seen in association with the use of certain drugs

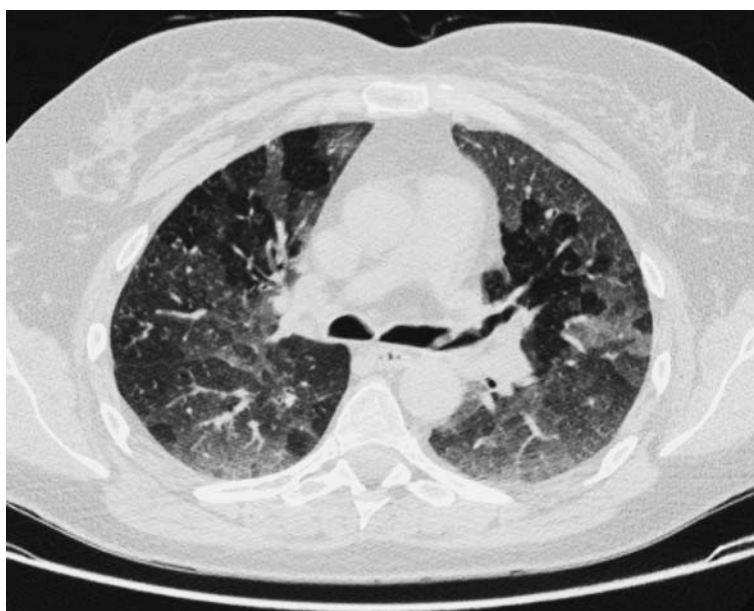
Idiopathic interstitial pneumonia type of reaction		Other types of interstitial lung disease	
Reaction	Prototypic drug(s)	Reaction	Prototypic drug(s)
Usual interstitial pneumonia (UIP)	Amiodarone, ergots, chemotherapy, nitrofurantoin, bleomycin, busulfan, methotrexate, doxorubicin, carmustine	Granulomatous interstitial lung disease	BCG, methotrexate
Fibrotic nonspecific interstitial pneumonia (NSIP)			
Cellular nonspecific interstitial pneumonia (NSIP)	Methotrexate, amiodarone, carmustine	Pseudosarcoidosis	Interferon
Desquamative interstitial lung disease (DIP)	Nitrofurantoin	Eosinophilic pneumonia	Antibiotics, nonsteroid anti-inflammatory drugs, ACE inhibitors, methotrexate, sulfasalazine, para-aminosalicylic acid, nitrofurantoin
Organising Pneumonia	Amiodarone, bleomycin, interferon, nitrofurantoin, methotrexate, cyclophosphamide, gold, busulfan	Alveolar filling with foamy macrophages	Amiodarone, mineral oil
Lymphocytic interstitial pneumonia (LIP)	Phenytoin	Pulmonary haemorrhage/hemosiderosis	Anticoagulants, fibrinolytic agents, penicillamine, propyl-thiouracil
Diffuse alveolar damage (DAD)	Chemotherapy, gold, methotrexate, bleomycin, aspirin, narcotics, busulfan, cyclophosphamide, carmustine	Proteinosis-like	Busulfan

## References

- Poll LW, May P, Koch JA et al (2001) HRCT findings of amiodarone pulmonary toxicity: clinical and radiologic regression. *J Cardiovasc Pharmacol Ther* 6:307–311
- Foucher P, Camus P (2006) The drug-induced lung diseases. [www.pneumotox.com](http://www.pneumotox.com). Cited 28 November 2006
- Rossi SE, Erasmus JJ, McAdams HP et al (2000) Pulmonary drug toxicity: radiologic and pathologic manifestations. *Radiographics* 20:1249–1259
- Vernhet H, Bousquet C, Durand G et al (2001) Reversible amiodarone-induced lung disease: HRCT findings. *Eur Radiol* 11:1697–1703



40.1



40.2

**Case 40**

CT shows extensive ground-glass attenuation in both lungs together with a few septal lines. Several areas of air trapping are seen on expiratory CT (40.2, 40.4).

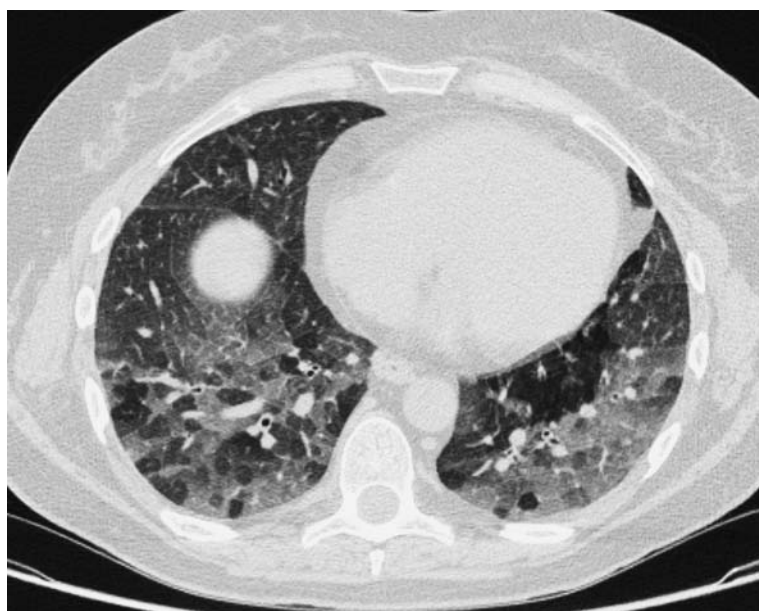
**Diagnosis****Desquamative interstitial pneumonia (DIP)**

DIP is due to intra-alveolar macrophage accumulation rather than desquamated pneumocytes, as its name suggests. DIP is associated with cigarette smoking and is thought to represent one end of a spectrum with respiratory bronchiolitis interstitial





40.3



40.4

lung disease (RB-ILD). However, DIP, in contrast to RB-ILD where accumulation of pigmented macrophages is limited to the lumen of the respiratory bronchioles and the lumen of adjacent alveoli, is characterised by the presence of numerous macrophages within the alveoli. This involvement is more or less uniform in severity within affected lobules. Interstitial inflammation and fibrosis are usually mild.

## CT Findings

### Appearance patterns:

- Increased attenuation:
  - Ground-glass

### Distribution patterns:

- Airspace
- Bilateral, peripheral and patchy or diffuse and uniform
- Basal predominance

### Associated findings:

- Findings of mild fibrosis
- Centrilobular emphysema
- Air trapping
- Intralobular reticular pattern

## References

- Caminati A, Harari S (2006) Smoking-related interstitial pneumonias and pulmonary Langerhans cell histiocytosis. *Proc Am Thorac Soc* 3:299–306
- Wittram C (2004) The idiopathic interstitial pneumonias. *Curr Probl Diagn Radiol* 33:189–199
- Wittram C, Mark EJ, McLoud TC (2003) CT-histologic correlation of the ATS/ERS 2002 classification of idiopathic interstitial pneumonias. *Radiographics* 23:1057–1071



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